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INFLUENCE OF ROADS ON THE SURROUNDING NATURAL ENVIRONMENT—VEGETATION, SOIL AND GROUND WATER

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A study for the purpose of demonstrating the qualitative and quantitative changes in the vegetation composition that can occur in connection with road construction or as an effect of traffic and road maintenance was carried out. The scattering of salt and heavy metals from highways was also studied. The studies were conducted at a number of observation regions, representing different vegetation types and varying geological, hydrological, and climatic conditions.

The effects of diminished water availability were revealed in several areas

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20. Abstract (cont'd)

where plants that require moisture exhibited a sharp decline. Mechanical effects were observed to be harmful to vegetation, most particularly in the case of road construction on bare alpine regions. Pollution effects on the vegetation could not be demonstrate within the regions investigated.

Five regions were selected for detailed studies on the influence of roads on the hydrogeological conditions. Four of the regions were located at highway projects where considerable excavation work was done during the course of the project, while one region involved an older highway where considerable tree die-off in connection with the road turned out to be due to high chloride contents in the ground water. Measurements of the ground water state were performed and ground water sampling and, in most cases, vegetation analyses were carried out.

The observations from the test regions and the accumulated literature data demonstrate that road construction and maintenance are the factors that primarily affect the ground water conditions. A drop in the ground water occurs partly in a direct manner due to excavations below the ground water level and partly in an indirect manner through a reduced infiltration and drainage measures. Impervious road banks cause damming, especially in swamp lands. The spreading of salt to combat slipperiness and to hold down the dust results in the pollution of the ground water near the highways under certain conditions. On the other hand, the general, continuous dispersion of pollutants from vehicular traffic was not demonstrated to pollute the ground water.

FOREWORD

The present report constitutes a summary of the botanical and hydrogeological studies conducted in the project, "The Influence of Roads on the Surrounding Natural Environment". The project was carried out at the National Road and Traffic Research Institute at Linköping and the Plant Ecology Department of the University of Lund.

The zoological studies conducted within the project were described in a separate report (SNV PM 1069). These studies were primarily conducted in the Zoology Department of the University of Lund.

The project was financed with support from the Research Board at the National Environmental Protection Agency and from the National Road and Traffic Institute.

Lars Bäckman

TABLE OF CONTENTS page

1. BACKGROUND

Road construction, maintenance, and traffic affect the surrounding natural environment in many different ways. How extensive this effect is and how it can be reduced or completely avoided are frequently subjects of discussion. However, the debate often becomes quite emotionally loaded, which to some extent is due to the fact that the answers to these questions have little basis in fact.

In an attempt to quantify the environmental effect of roads and thus also improve the basis in fact, this project, "The Effect of Roads on the Surrounding Natural Environment", was begun in the autumn of 1973 on the initiative of Gert Knutsson. The project has been going on for 4 years and was financially supported partly by the Research Board of the National Environmental Protection Agency and partly by the National Road and Traffic Institute (VTI).

The original purpose of the project was an attempt to quantify the effect of roads on the surrounding environment, primarily changes in the plant and animal life and water conditions as well as pollution effects in the soil and water. The goal did not include the effect of roads on heavily populated environments or on cultivated areas.

Certain limitations were thus imposed from the very beginning so that the scope of the problem considered would not be too great. Further limitations were subsequently imposed as a result of the preliminary investigation and literature review that was conducted (SNV PM 476 & VTI Report No. 54). Wild deer were omitted from the zoological study since reaearch in this respect had already been carried out at Stockholm University (Wild animal accident project VIOL). The effects of long road embankments on lakes and shallow ocean bays were not studied either since this was considered to be a complex problem that required special economic and personnel resources. Due to the fact that surface-water problems in heavily populated areas have been treated in several BFR-sponsored projects, no studies on surface-water contamination from highways were carried out within this project. In addition, the literature review revealed that there have been a comparatively large number of studies on the accumulation of heavy metals in the soil and vegetation in the vicinity of roads. As a result, the National Environmental Protection Agency did not consider soil sampling necessary in the project. Consequently, soil sampling was done only during the first year of the project.

Research results have been published privately in reports, the introductory literature surveys (SNV PM 476 and VTI Report No. 54) and two situation reports (VTI Internal Reports Nos. 201 and 251). In addition, some partial results have been published in the Nordic IHD Report No. 8 and Fauna och flora, No. 1, 1976.

The project was presented at the Twelfth Nordic Geology Winter Conference in Göteborg (Knutsson, 1976) and the Thirteenth Nordic Symposium on Water Research in Röros (Engquist, 1977).

The research results were also discussed with the previous researchers for various environmental protection interests and with representa-

tives of the National Highway Department, upon various occasions, such as discussion meeting in Stockholm in May 1976.

During the course of the project it turned out that the zoological aspect was quite distinct from the other aspects of the project. Also, because the final report was expected to be voluminous, it was considered convenient to divide it into two parts. The studies concerning soil and vegetation as well as ground water were contained in the first part. The second part included the zoological studies.

2. VEGETATION AND SOIL

A study is presented in this section, whose purpose was to demonstrate the qualitative and quantitative changes in vegetation composition that can occur in connection with road construction or as an effect of traffic and road maintenance. The dispersion of salt and heavy metals from highways was also studied, primarily in order to determine whether there is a connection between the degree of pollution and a possible change in the vegetation.

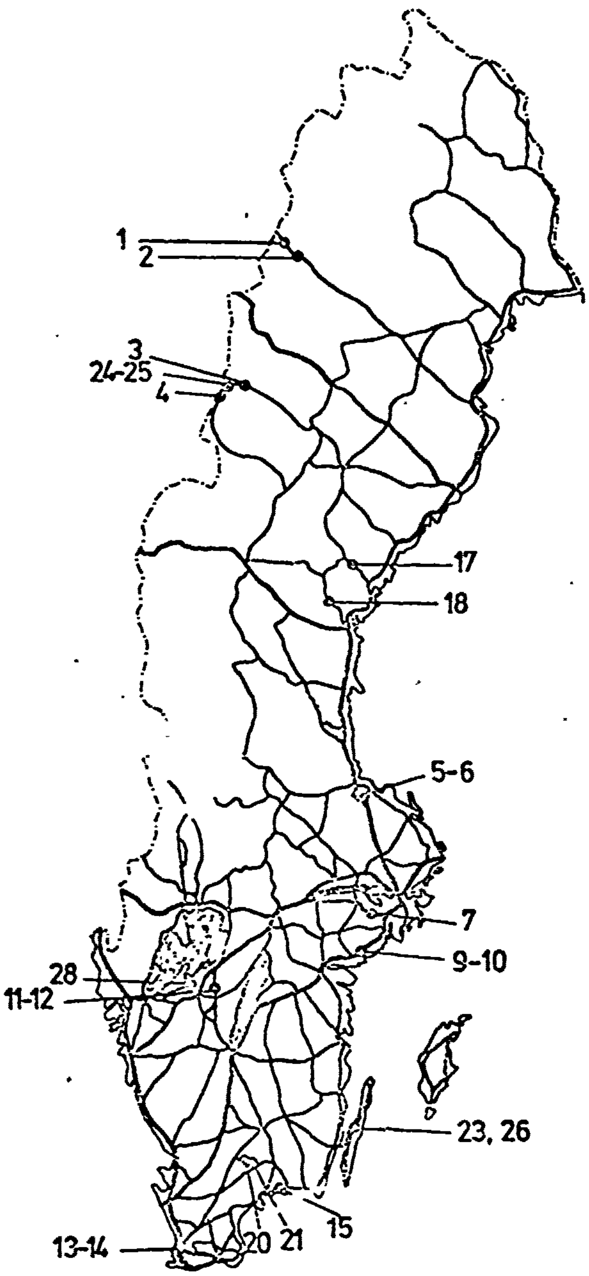
The field studies were oriented toward a number of observation sites (Fig. 1), selected so as to represent a number of different vegetation types, as well as varying geological, hydrological, and climatic conditions. One basic requirement in the selection of the observation sites was that they should be oriented toward sections of roads where the construction work would just be beginning, so as to make it possible to perform measurements before and after construction and after the road had been subject to vehicular traffic for a couple of years.

2.1. Methods

2.1.1. Vegetation

Wherever it was possible to lay out large homogeneous observation zones, the test points in them were usually located at four different distances from the road. The most distant test point thus represents an environment that probably is unaffected by the road construction, maintenance, and traffic. At each test point the percentual coverage by plants was evaluated inside of 4 square-meter squares. The need for comparable soil and vegetation conditions in many cases limited the size of the observation zones, such that it was not always possible to lay out the test points in accordance with this system. In those cases the vegetation composition was monitored inside of 10 x 10 m areas in the vicinity of the road line. The vegetation analysis usually included an evaluation of the composition over the entire surface, but in some cases it was done inside of square-meter squares selected at random inside of the large square.

As soon as the project was started, it became clear that the activity planned would result in very comprehensive data material from the vegetation analyses. In order to handle this material, it was desirable to utilize data-based routines. Contact was made in 1973 with Lars Österdahl, Biodata, in order to obtain information on the



Figur 1. Observationsområden för mark- och vegetationsanalys. (Study sites for analyses of soil and vegetation)

RUBIN system that he developed. The result was that the work to convert the incorporation program of the RUBIN system for use in the Lund data central was begun in 1974. The input program was then further developed and various processing programs were produced. Some of them are described in Danielsson & Rühling, Rühling [2,3].

All the vegetation data material is thus documented in a uniform manner and stored on magnetic tape, such that it is readily accessible when needed in the future.

For vascular plants the nomenclature follows the Code List B3, for leaf mosses, the Code List M1, for liverworts, Arnell, and for lichens, Krok-Almqvist [4,5,6,7]. The determination of certain lichens and mosses that occur only in small numbers in the analysis squares was sometimes carried only to the family level.

All the vegetation analyses (218 Tables) are given in an Appendix of which only a few copies were produced (one of which is kept at VTI) for this report; a few of special interest are also given in the following.

The Tables give the species classified into systematic groups: lichens, mosses, ferns, gramineae, and other vascular plants. The measurement values refer to the percentual coverage of the ground surface by the plants. Below 10%, it was evaluated at ± 1%; above 10%, at ± 10%. Columns F, C, and M indicate the frequency (% of squares where the species is present), the characteristic degree of coverage (mean value of degrees of coverage different from zero), and the mean coverage (mean value of degree of coverage), respectively.

The map information indicates the 100 x 100 m square in the national network, within which the study zone lies. The alphanumeric form for coordinate information as described in the principal RUBIN manual [8] is used.

The number of the observation zone is given in the Table heading. Other analysis cases within a zone are distinguished by adding the number 100 to the zone number.

2.1.2. Soil

Soil samples were taken from the 0-10 cm level with the aid of a steel cylinder. Three samples were collected at each measuring point. In the laboratory they were sifted through 6 mm mesh sieve and combined before analysis. The Pb content was measured after extraction with EDTA solution, sodium and ammonium acetate extract, and chloride and water extract. The methods used are described in greater detail in Ref. 9. The analytical results were calculated in mg/g of dry substance and given in the Tables in connection with the respective region description (Section 2.2.).

2.1.3. Moss

The moss samples collected were cleansed so that only the growth of the last 2-3 years was taken for analysis. The moss sample, dried

at ca. 40°C, was dissolved with a mixture of nitric acid and perchloric acid. Lead, nickel, and vanadium were analyzed with the atom absorption technique in the solution thus obtained. The results were calculated in μg/g of dry substance and reported in Section 2.2.

2.2. Description of the observation zones

The individual observation zones and the scope and results of the studies within them are described in the following. In most cases the annual mean 24-hour traffic (ADT) was specified. The ADT value was obtained from the traffic calculations for 1975 [1].

During the relatively short activity time for the project, obvious changes in the flora were observed in only a few cases. More long-term effects probably were not yet so manifest that they could be recorded with the methods used. Therefore, it would be expedient if further analyses were carried out within the observation zones after a few years. In order to facilitate this, the following zone descriptions were quite detailed.

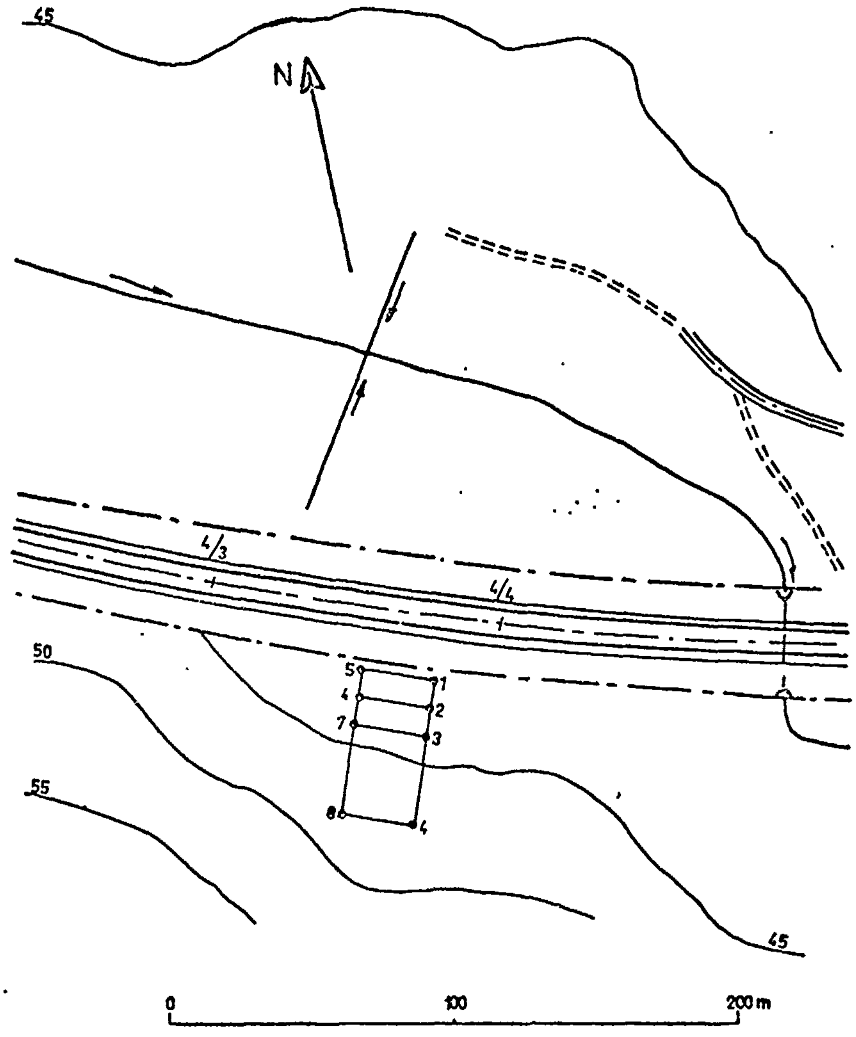
2.2.1. Kvartinge, Stockholm province, district 7, Road E3, Strängnäs-Södertälje, part Läggesta-Nygård, section 4/355-4/380, ADT 8250

The observation zone lies south of the high road embankment and in a slope down toward the road. Eight measurement points were laid out along two lines perpendicular to the road (Fig. 2).

The soil is brown soil and the soil type is sandy moraine that is covered with a thin layer of sediment closest to the road.

The vegetation consists of a spruce forest with a well-developed moss cover, primarily house moss and hook moss. The field layer is sparse with mainly blueberries, lingon berries, and sorrel. The vegetation analyses were carried out in 1973 immediately prior to opening the road to traffic, and in 1976. During the initial analysis, soil samples were also taken, which exhibited the following concentrations:

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	9,4	45,9	9,9
2	7,2	57,5	11,3
3	9,6	31,2	16,7
4	11,5	29,0	16,3
5	8,7	39,5	19,5
6	6,8	9,3	9,6
7	5,2	17,5	7,1
8	11,6	31,4	17,7



Figur 2. Observationsområde Kvartinge (nr 7).
E3, Södertälje - Strängnäs. (Study site Kvartinge (No 7). Road E3, Södertälje - Strängnäs).

House moss samples were collected in 1973 at the measuring points where it was present in larger amounts and analyzed for heavy metals:

Measuring point	Lead (mg/kg)	Nickel (mg/kg)	Vanadium (mg/kg)
1	28	10	21
4	41	3,3	8,4
5	37	5,0	12
7	46	4,5	9,2
8	40	6,7	8,0

2.2.2. Tystberga, Södermanland province, districts 9-10, Road E4, Nyköping-Lästringe, section 14/000-14/140, ADT 9000

The measuring points were laid out, partly within a zone (No. 9) above a mountain cut east of the road, and partly within a zone (No. 10) west of the road, which passes through a ground cut. The soil type west of the road consists of a sandy moraine. The mountain is exposed 30 m from the wild-animal fence, which means that the soil depth is relatively shallow. East of the road, the mountain is covered with only a thin soil cover (Fig. 3).

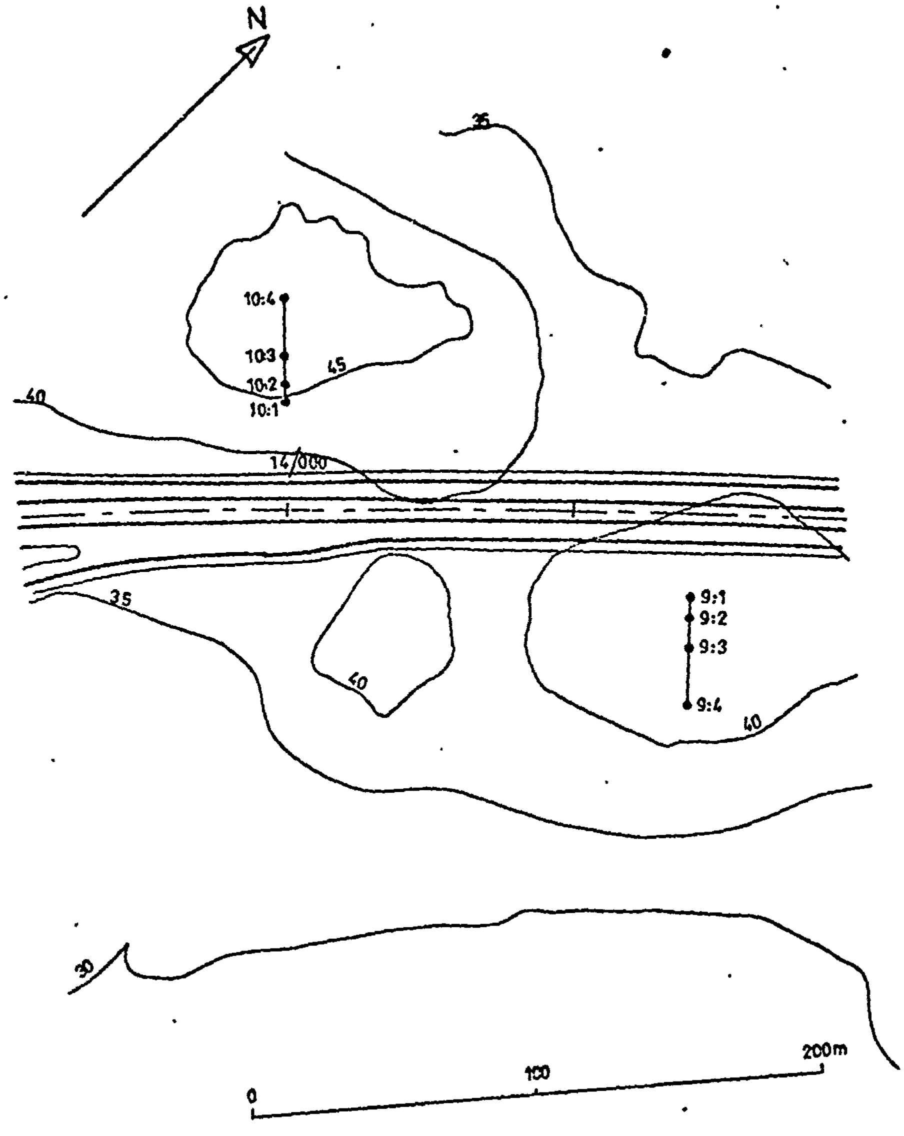
The vegetation consists of a mixed pine forest, where the field layer is very species-poor and is dominated by curly grass.

Soil analysis was carried out in 1973, immediately after the road was opened, and in 1975. The following results were obtained:

Measuring point	Lead (mg/kg)		Sodium (mg/kg)		Chloride (mg/kg)	
	1973	1975	1973	1975	1973	1975
9:1	36	53	60	120	99	15
9:2	31	33	32	84	55	29
9:3	32	41	35	77	59	105
9:4	14	62	21	78	36	134
10:1	24	25	25	44	23	13
10:2	36	33	47	62	46	24
10:3	34	44	82	68	97	21
10:4	32	63	24	93	26	61

A moss sampling was effected in 1973, when wall moss samples were collected and analyzed with the following results:

Measuring point	Lead (mg/kg)	Nickel (mg/kg)	Vanadium (mg/kg)
9:1	40	7,2	16
9:2	48	6,8	13
9:3	40	4,9	13
9:4	36	5,4	17
10:1	45	7,1	21
10:2	54	7,7	22
10:3	50	8,1	24
10:4	48	6,2	20



Figur 3. Observationsområde Tystberga (nr 9 och 10). E 4, Nyköping - Lästringe. (Study site Tystberga (No 9 and 10). Road E 4, Nyköping - Lästringe).

2.2.3. Potteboda, Kronoberg province, district 20. Road 120, Älmhult-Tingsryd, division Håradsmåla-Potteboda, section 9/700--9/800, ADT ca. 500

The observation zone consists of a small peatmoss bog through which the new road runs. Eight measuring points were laid out in connection with the pipes for water level measurements on both sides of the road line (Fig. 4). The zone is described in greater detail in Section 3.2.2. The vegetation can be described as a pine peatmoss which includes both extremely lean marsh as the initial phase in pure bog vegetation. Priophorum vaginatum dominates in the field layer, but Ledum palustre, Vaccinium oxycoccus, Erica tetralix, and Rubus chamaemorus are also abundantly present. The bottom layer consists of peat mosses, primarily Sphagnum angustifolium, fallax, imbricatum, magellanicum, pulchrum, and majus. The northern part of the zone is taken up by a Carex lasiocarpa-dominated lean marsh—an indication of a peripheral marsh.

Vegetation analyses were performed in 1974 and 1977. The excavation work was begun in the fall of 1976 and the road was opened to traffic in June 1977. During excavation of the bog material was piled upto the road line and spread out over the bog so that several measuring points (Nos. 1, 2, 4, and 5) were destroyed. No vegetation changes could be observed at the intact test points during the short time that had elapsed since the road was completed.

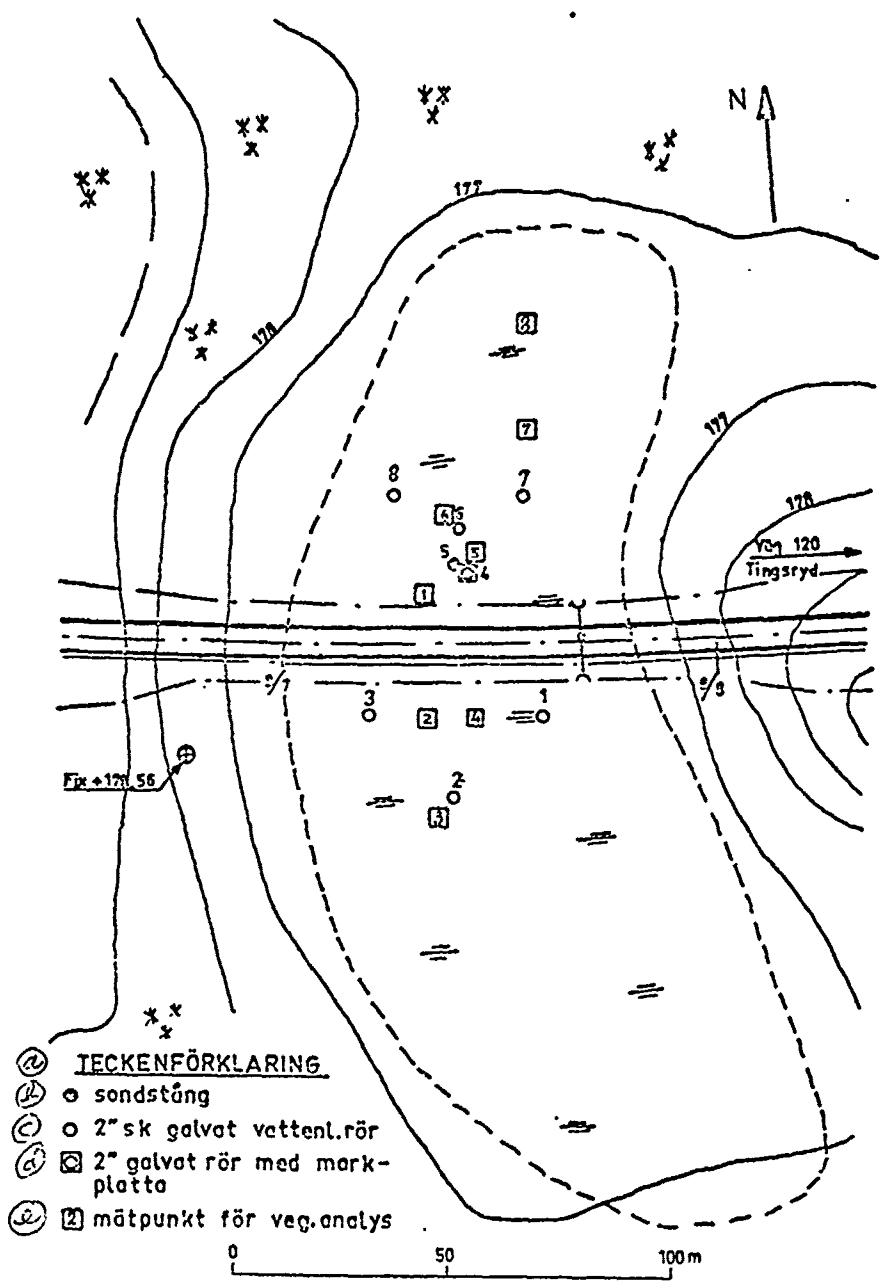
2.2.4. Svenslund, Kronoberg province, district 21. Road 120, Älmhult-Tingsryd, division Håradsmåla-Potteboda, section 10/400-10/550, ADT ca. 500

The observation zone comprises a bog complex with adjacent forest on a peat base. Seven measuring points were laid out in the vicinity of the pipes for water level measurements that are located on both sides of the road (Fig. 5). The geology and hydrology of the zone are described in Section 3.2.2.

Measuring points 2, 4, and 7 lie in a pine forest with a shrub-dominated field layer of heather and lingon. The other measurement points lie in marsh vegetation; Nos. 1 and 5 are dominated completely by Narthecium ossifragum, together with Carex lasiocarpa. The bottom layer consists of scattered clumps of peat moss. The vegetation at points 3 and 6 more closely resembles the swamp vegetation at Potteboda with inclusion of Priophorum vaginatum and a well-developed bottom layer of peat mosses (Sphagnum angustifolium, fuscum, fallax, imbricatum, magellanicum, pulchrum, and rubellum).

The vegetation analysis was carried out in the fall of 1974 and 1977. As at Potteboda, the excavated material was piled up near the road and spread out over large areas and covered several measuring points (Nos. 1-3). No vegetation changes could be detected during the year that elapsed since the road construction began.

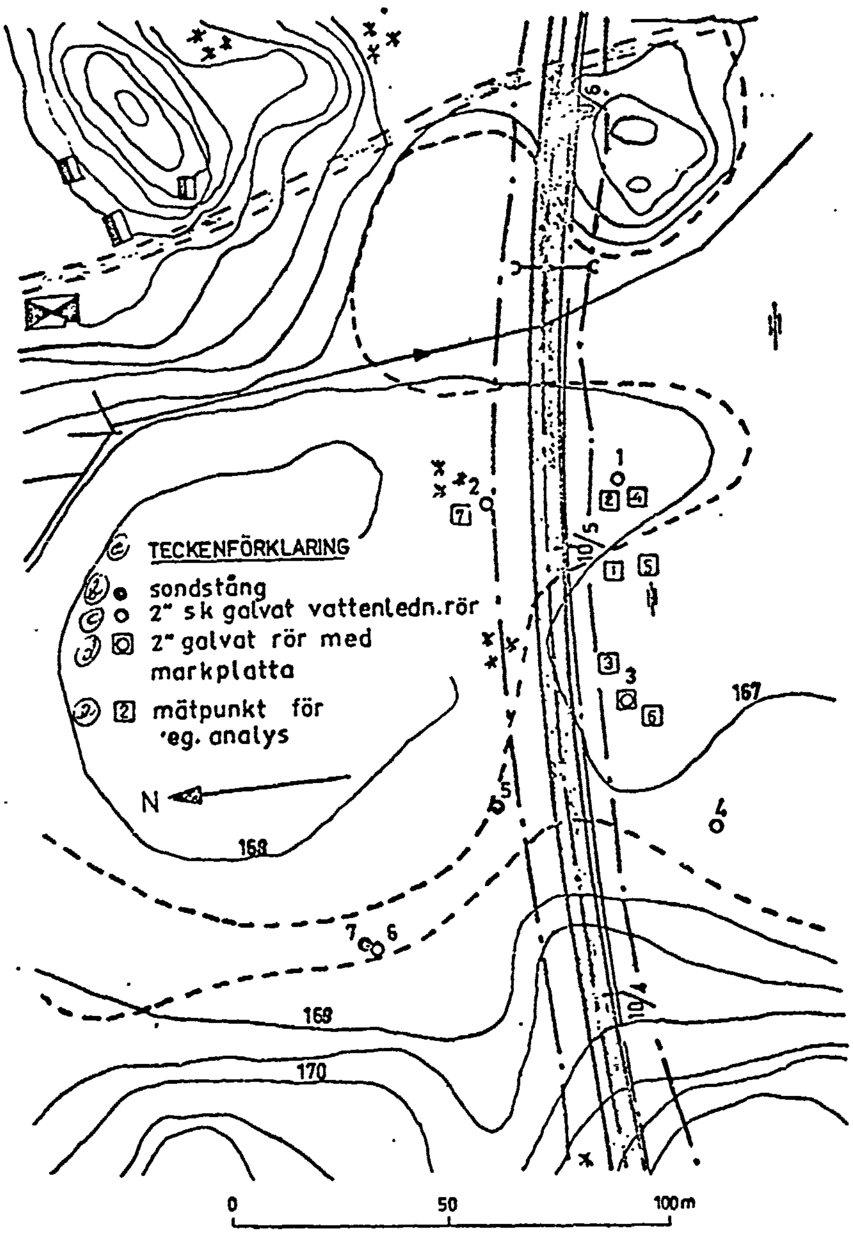
2.2.5. Kalleguta, Kalmar province, district 26. Road 979, Köpingsvik-Löt, division Köpingsvik-Laxeby, section 3/200-3/720



Figur 4. Observationsområde Potteboda (nr 20). Väg 120, Älmhult-Tingsryd (Study site Potteboda (No 20). Road 120, Älmhult-Tingsryd).

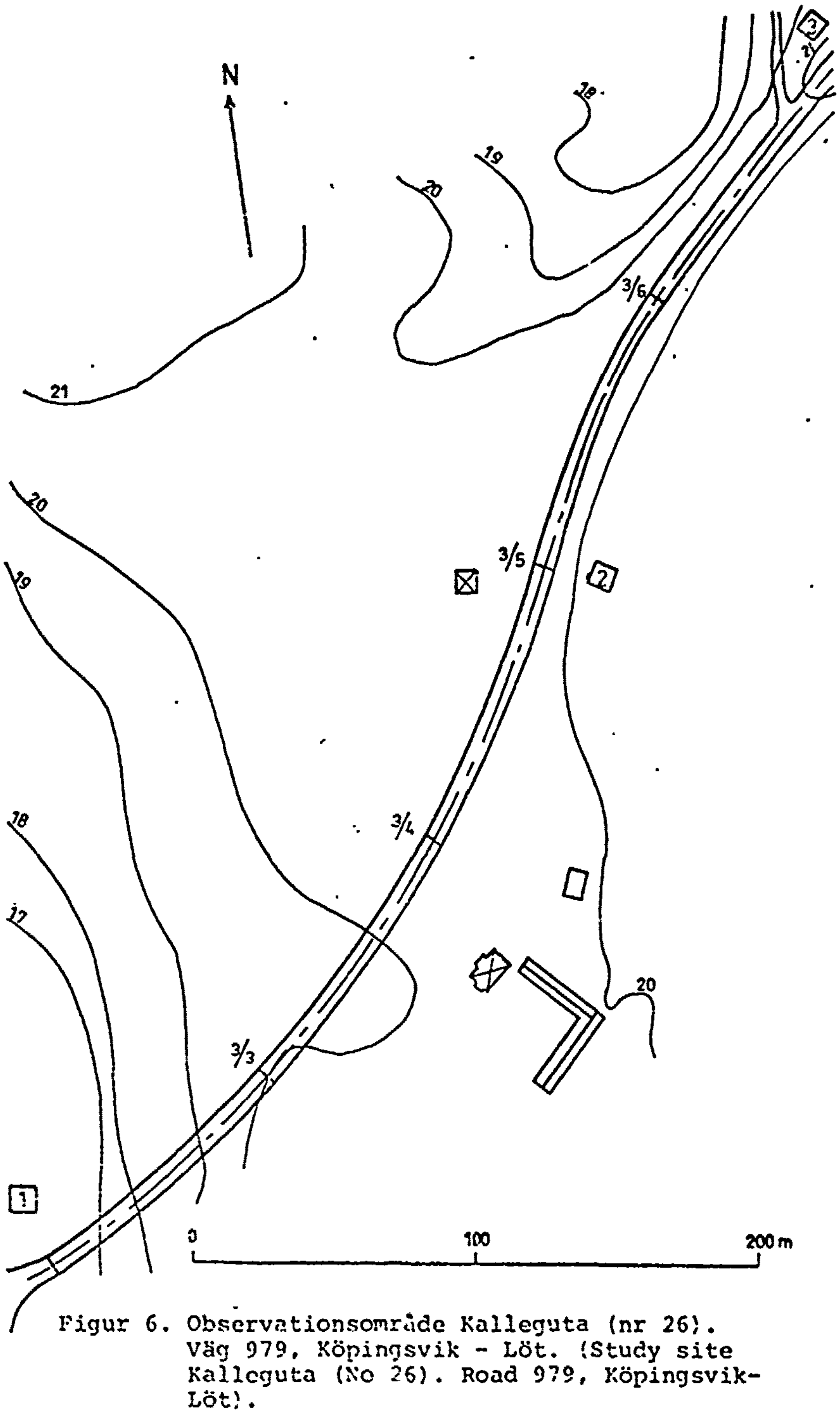
Key: (a) Table of signs (b) sounding rod (c) 2" galvanized water pipe (d) 2" galvanized pipe with soil-level indicator* (e) measuring point for vegetation analysis.

*Literally "ground plate"--Translator's note

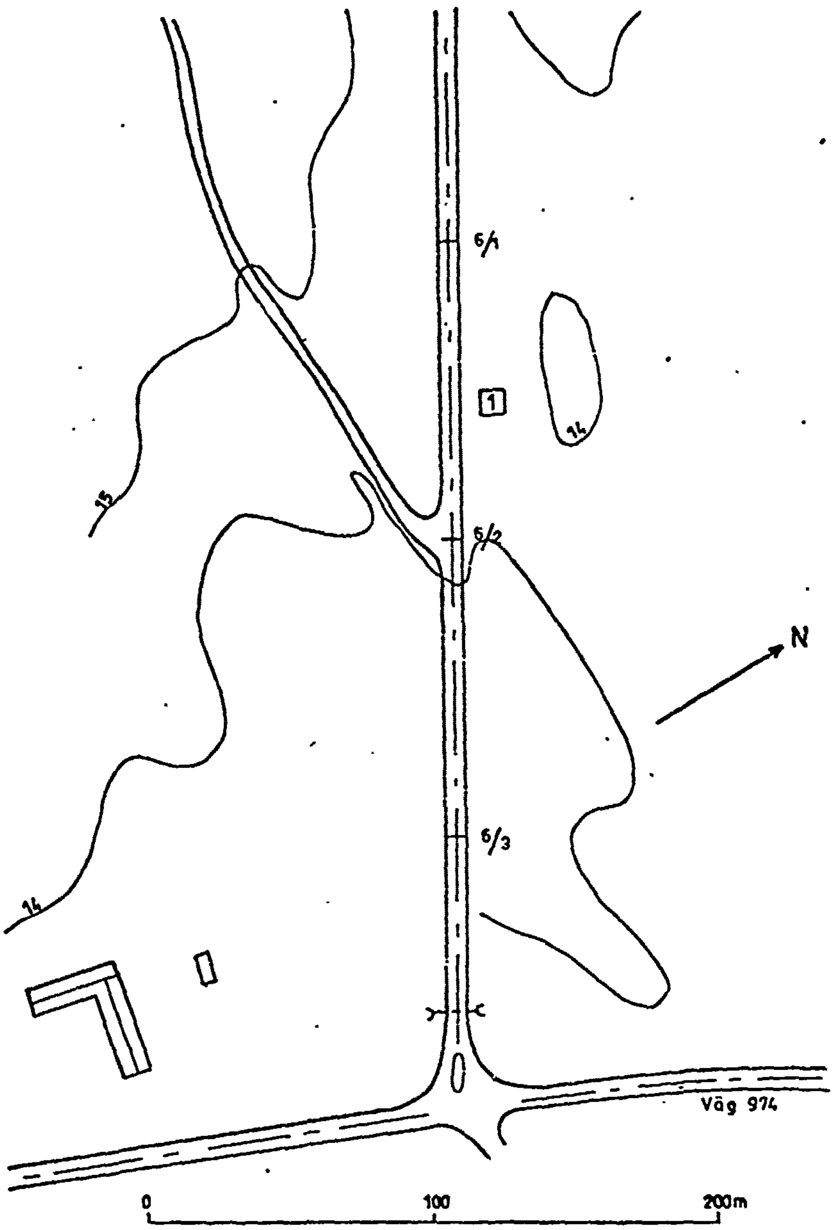


Figur 5. Observationsområde Svenslund (nr 21). Väg 120, Älmhult-Tingsryd. (Study site Svenslund (No 21) Road 120, Älmhult-Tingsryd.)

Key: (a) Table of signs (b) sounding rod (c) 2" galvanized water pipe (d) 2" galvanized pipe with soil-level indicator (e) measuring point for vegetation analysis



Figur 6. Observationsområde Kalleguta (nr 26). Väg 979, Köpingsvik - Löt. (Study site Kalleguta (No 26). Road 979, Köpingsvik-Löt).



Figur 7. Observationsområde Laxeby (nr 26:4).
Väg 980, Laxebygatan. (Study site Laxeby
(No 26:4). Road 980, Laxebygatan.)

The observations were made within 10 x 10 m partial zones (Fig. 6). The substratum consists in all cases of a limestone-rich moraine. There is a well-developed humus in zone 1. Partial zones 1 and 2 lie below the road, while partial zone 3 lies somewhat above it.

The partial zone 1 is overgrown with birch, together with ash, hazel, spindle trees, hawthorn, and sloe. Raspberry, dewberry, hairy violet, clove, and carrot are noted in the field layer.

The vegetation in zone 2 consists of a dense juniper growth. The field layer is quite species-rich and Sesleria coerulea plays the most prominent role there, while the bottom layer is dominated by golden curl moss.

Zone 3 is a sparse and dry juniper growth where the field layer is dominated by hairy oats. Field wormwood, Anthyllis vulneraria, thyme, spring Potentilla, and yellow stonecrop are noted among the plants.

The vegetation analysis was carried out in October 1975 and in July 1977. The road was subsequently rebuilt in 1975-76. No appreciable changes in the vegetation could be observed during the observation period.

The following Table gives the results of the analyses on soil samples collected in 1975.

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	8	112	36
2	10	117	20
3	6	33	17

2.2.6. Laxeby, Kalmar province, district 26:4. Road 980, Laxebygatan (Laxeby), section 6/150

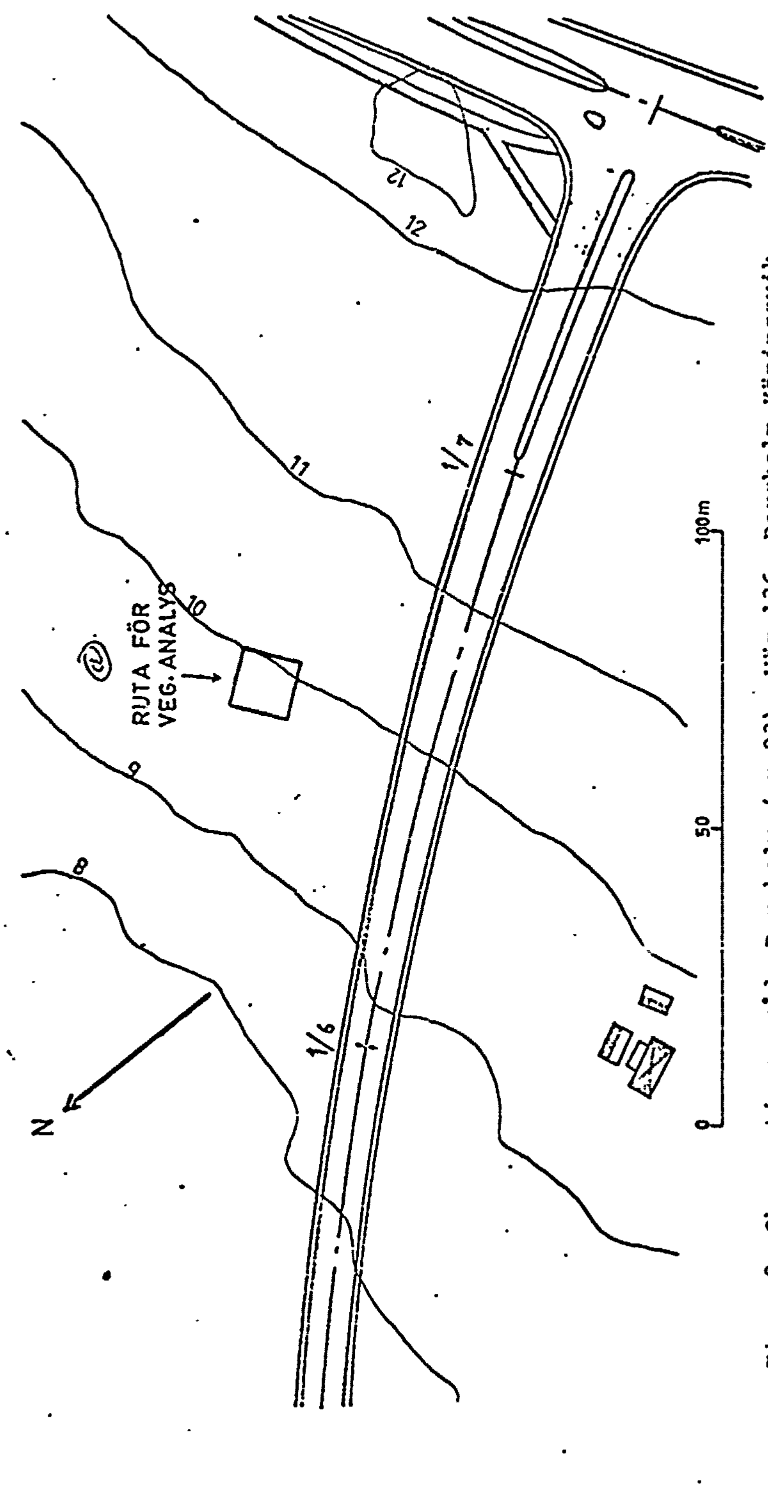
The observation zone consists of a 10 x 10 m surface that lies ca. 10 m north of the road edge (Fig. 7). The soil type is a limestone-rich moraine.

The vegetation type is a dry meadow with scattered junipers. The field layer is dominated by the grasses, hairy oats, Festuca ovina, and quaking grass. Many herbs are present, for example, Anthyllis vulneraria, ground thistle, Fragaria collina, cowslip, and thyme.

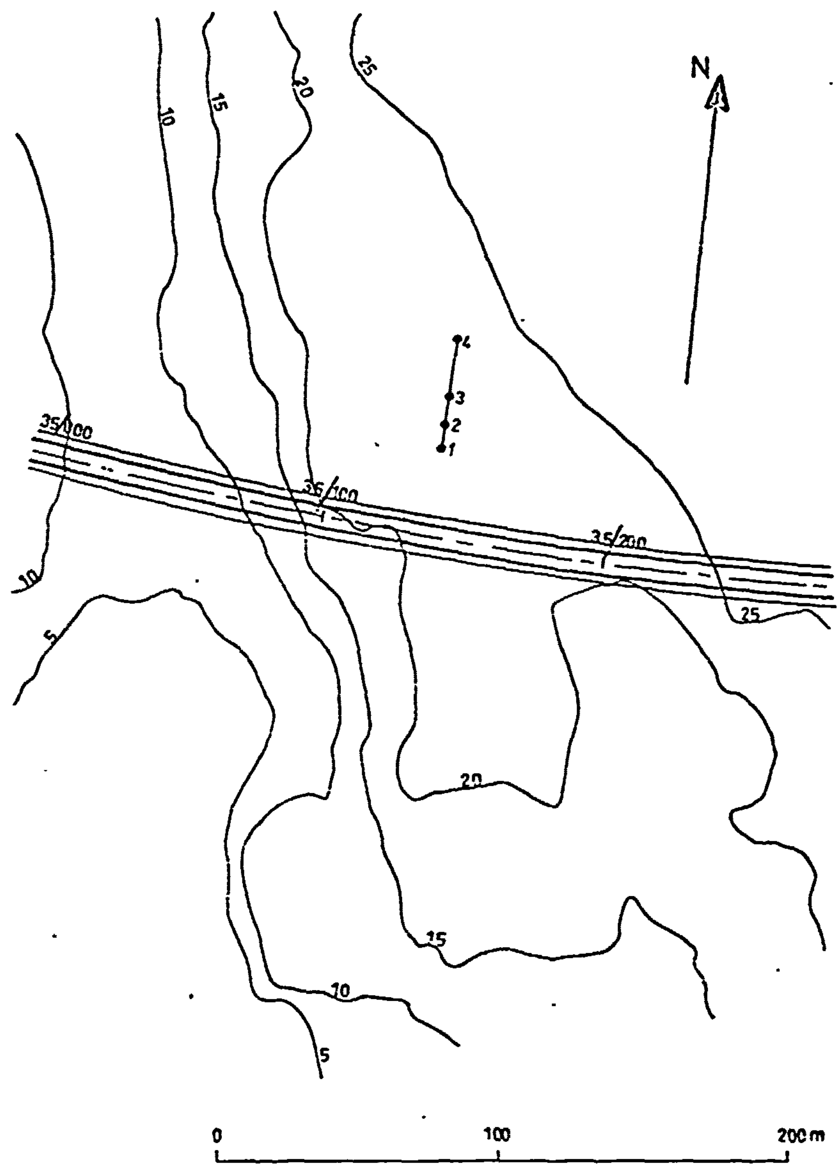
The vegetation analysis was carried out in October 1975 and July 1977. Rebuilding of the road was completed in 1976. No vegetation changes could be observed during the brief period that had elapsed since the last analysis.

2.2.7. Borgholm, Kalmar province, district 23. Road 136, Borgholm-Köpingsvik, section 1/300, ADT 4100

The observation zone lies east of the road line and at a lower level than the future road (Fig. 8). The soil type is a calcareous moraine.



Figur 8. Observationsområde Borgholm (nr 23). Väg 136, Borgholm-Köpingsvik
(Study site Borgholm (No 23). Road 136, Borgholm-Köpingsvik.)
Key: (a) area for vegetation analysis



Figur 9. Observationsområde Gundlatorp (nr 15). Rv 15, Karlshamn - Ronneby, (Study site Gundlatorp (No 15). Road 15, Karlshamn - Ronneby).

The vegetation type is a lime wet meadow, dominated by blue grass and Sesleria coerulea. Bloodroot, Priophorum vaginatum, * * and * were noted among the plants. Drepanocladus and Scorpidium species are present in the bottom layer. The vegetation analyses were carried out in five 1 m^2 squares laid out at random within a 10 x 10 m surface. Analyses were made in July 1975 and 1977. Construction was supposed to begin in 1975, but was postponed until the fall of 1977. The second analysis thus represents the situation immediately prior to the beginning of construction.

2.2.8. Gundlatorp, Blekinge province, district 15. Road 15, Karlshamn-Ronneby, Åryd-Bräkne-Hoby portion, section 35/138, ADT 5450

The observation zone lies above a high cut north of the road. It is rich in boulders, but relatively level. The soil is brown soil and the soil type a swelling moraine. Four measuring points were laid out along a line perpendicular to the road (Fig. 9).

The vegetation consists of a foliferous mixed forest with oak, maple, and birch. A heavy shrub layer of hazel with the incursion of hawthorn and birch is present. The first vegetation analysis was carried out in May 1974 when the excavation work was in progress. Soil samples were also collected on this occasion. The road was opened to vehicular traffic in the fall of 1975 and the vegetation analysis was repeated in May 1976. It was then found that the vegetation had undergone a substantial change near the cut. Many species typical of open, dry land had appeared or increased their proportion: e.g., Hieracium pilloselloidea and vulgata, speedwell (Veronica chamaedrys and officinalis), curly grass (Deschampsia flexuosa), and Agrostis tenuis, while hazel (Corylus avellana) and sorrel (Oxalis acetosella) had diminished (Tables 1 and 2). On the site above the cut with a southern exposure a pronounced drying of the soil had taken place, probably caused primarily by an improved drainage, but also by the increased admission of light.

Analysis of the soil samples collected in 1974 yielded the following results:

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	11	11	3,4
2	15	14	3,8
3	14	15	4,4
4	16	9,2	6,3

2.2.9. Holmeja, Malmöhus province, district 13. Road 816, Holmeja-Sturup, section 2/655

The observation zone is level and located north of the road and at a lower level than the road. Four measuring points were laid out at different distances along a line perpendicular to the road (Fig. 10).

The soil is brown soil and the soil type moraine clay. Nearest the road the humus debris had been blown by the wind and deposited

*We were unable to find the English equivalents for these plant names--Translator's note

further in (in the vicinity of measuring point 4), where it forms a quite thick layer.

Table 1. Analyses of Vegetation at Study Site Gundlatorp in May 1974 during Excavation

Province K Road 15 Point 1

Year: 1974, week: 22, day: 1
Map indication: 3F6A 1842
Overlay status
Region: 15

	1	2	3	4	F	C	M
ANEMONE NEMOROSA	0	1	0	0	25.	1.	.3
CERASTIUM SEMIDECANDRUM	1	0	0	0	25.	1.	.3
CORYLUS AVELLANA	30	50	20	70	100.	42.	42.5
OXALIS ACETOSELLA	1	1	0	0	50.	1.	.5
QUERCUS ROBUR	0	1	0	0	25.	1.	.3
RANUNCULUS ACRIS	1	0	0	0	25.	1.	.3
ROSA SP.	0	1	0	0	25.	1.	.3
RUBUS IDAEUS	1	1	1	0	75.	1.	.8
VERONICA CHAMAEDRYS	1	1	2	1	100.	1.	1.3
VIOLA CANINA	1	1	1	0	75.	1.	.8
ANTHOXANTHUM ODORATUM	1	1	1	0	75.	1.	.8
FESTUCA RUBRA	0	0	0	2	25.	2.	.5
HYPNUM CUPRESSIFORME	1	10	0	0	50.	5.	2.7
number of species per square --- ANTAL ARTER PER RUTA	9	10	5	3			

TOTALT ANTAL ARTER = 13
total number of species

Table 2. Analyses of Vegetation at Study Site Gundlatorp, performed in May 1976 after the Road had been used for one year

Province K Road 15 Point 1

Year: 1976, week: 21, day: 4
Map indication: 3F6A 1842
Overlay status
Region: 115

	1	2	3	4	F	C	M
ANEMONE NEMOROSA	0	0	0	1	25.	1.	.3
CERASTIUM SEMIDECANDRUM	2	1	0	0	50.	1.	.8
CORYLUS AVELLANA	0	0	0	1	25.	1.	.3
CRATAEGUS OXYACANTHA	0	1	0	0	25.	1.	.3
HIERACIUM PILOSELLOIDEA /COL	1	0	0	0	25.	1.	.3
HIERACIUM VULGATA /COLL	0	0	0	1	25.	1.	.3
MELAMPYRUM PRATENSE	0	1	0	2	50.	1.	.8
MOEHRINGIA TRINERVIA	0	1	0	1	50.	1.	.5
PRUNUS SPINOSA	0	0	1	1	50.	1.	.5
QUERCUS ROBUR	0	1	0	1	50.	1.	.5
RANUNCULUS ACRIS	1	1	0	0	50.	1.	.5
ROSA SP.	0	0	0	1	25.	1.	.3
RUBUS IDAEUS	1	1	1	1	100.	1.	1.0
SENECIO VISCOSUS	0	1	1	1	75.	1.	.8
VERONICA CHAMAEDRYS	1	2	5	30	100.	9.	9.5
VERONICA OFFICINALIS	1	0	3	0	50.	2.	1.0
VIOLA CANINA	1	1	1	2	100.	1.	1.3
AGROSTIS TENUIS	5	1	1	1	100.	2.	2.0
ANTHOXANTHUM ODORATUM	2	2	5	2	100.	3.	2.7
DESCHAMPSIA FLEXUOSA	20	1	0	0	50.	10.	5.2
FESTUCA RUBRA	1	1	1	0	75.	1.	.8
BRACHYTHECIUM SP.	1	0	0	0	25.	1.	.3
HYPNUM CUPRESSIFORME	1	0	0	0	25.	1.	.3
MNIUM AFFINE	1	0	0	0	25.	1.	.3
POLYTRICHUM JUNIPERINUM	1	0	1	0	50.	1.	.5
RHYTIDIADELPHUS SQUARROSUS	1	1	0	0	50.	1.	.5
TORTULA RURALIS	1	1	0	0	50.	1.	.5
ANTAL ARTER PER RUTA	17	16	10	14	number of species per square		

TOTALT ANTAL ARTER = 27 total number of species

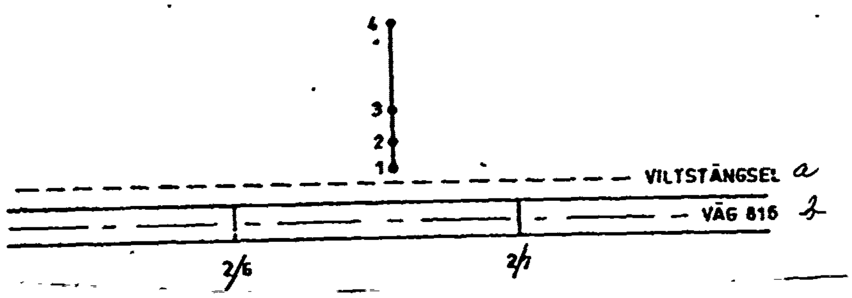


Fig. 10. Sketch of study site Holmeja (No. 13). Road 816, Holmeja-Sturup.

Key: (a) wild animal fence (b) road 816

The vegetation type is a species-lean heath with a very sparse field layer of wood anemone, lily of the valley, and two-leaved maianthemum. The vegetation was analyzed in the spring of 1974 and 1976. The road was opened to vehicular traffic in the summer of 1974.

At measuring point 1, closest to the road, <u>Poa nemoralis</u> and <u>Agrostis tenuis</u> had increased markedly, probably an effect of greater light admission (Table 3). Otherwise, no differences were noted in the composition of the vegetation.

Analyses of the soil samples from the 0-10 cm level yielded the following results:

Measuring point	Lead (mg/kg)			Sodium (mg/kg)			Chloride (mg/kg)		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
1	32	18	20	26	15	27	17	8,7	39
2	43	23	15	51	12	22	39	7,5	32
3	46	16	37	46	15	33	61	8,4	35
4	85	7[illegible]	87	99	146	123	102	42	76

The contents are consistently the highest at measuring point 4, due to the fact that the content of organic material there is considerably higher than at the other measuring points. The variation is consistently large, and it is impossible, e.g., to demonstrate any accumulation of the analyzed substances during the measurement period.

2.2.10. <u>Sturup, Malmöhus province, district 14. Road 816 Holmeja-Sturup, section 3/230</u>

The observation zone is level and located south of the road at a somewhat lower level than the road. Four measuring points were laid out at different distances along a line perpendicular to the road (Fig. 11).

Tabell 3. Vegetationsanalys vid observationsområde Holmeja. (Analyses of vegetation at study site Holmeja.)

LÄN M VÄG 816 PUNKT 1 — province M, road 816, point 1

ÅR 1976 VECKA 20 DAG 4 — 1976, week 20, day 4
KARTANGIVELSE 2021 1425 — map indication 2021 1425
BELÄGGSTATUS — overlay status
OMRÅDE 13 — district 13

	1	2	3	4	F	C	M
ANEMONE NEMOROSA	5	30	2	1	100.	9.	9.5
CONVALLARIA MAJALIS	20	5	5	2	100.	8.	8.0
FAGUS SILVATICA	100	100	50	100	100.	88.	87.5
MAIANTHEMUM BIFOLIUM	0	0	0	1	25.	1.	.3
VIOLA CANINA	1	1	1	0	75.	1.	.8
LUZULA PILOSA	1	1	0	0	50.	1.	.5
POA ANNUA	2	1	3	5	100.	3.	2.7
POA NEMORALIS	2	0	0	1	50.	1.	.8
No. of species per square ANTAL ARTER PER RUTA	7	6	5	6			

Total no. of species
TOTALT ANTAL ARTER = 8

LÄN M VÄG 816 PUNKT 1

ÅR 1976 VECKA 23 DAG 2
KARTANGIVELSE 2021 1425
BELÄGGSTATUS
OMRÅDE 113

	1	2	3	4	F	C	M
ANEMONE NEMOROSA	2	2	3	2	100.	2.	2.2
CONVALLARIA MAJALIS	40	30	30	10	100.	27.	27.5
FAGUS SILVATICA	90	90	90	90	100.	90.	90.0
MAIANTHEMUM BIFOLIUM	0	1	0	0	25.	1.	.3
AGROSTIS CANINA	0	0	10	20	50.	15.	7.5
POA ANNUA	2	1	2	0	75.	2.	1.3
POA NEMORALIS	3	4	30	20	100	14.	14.2
No. of species per square ANTAL ARTER PER RUTA	5	6	6	5			

Total no. of species
TOTALT ANTAL ARTER = 7

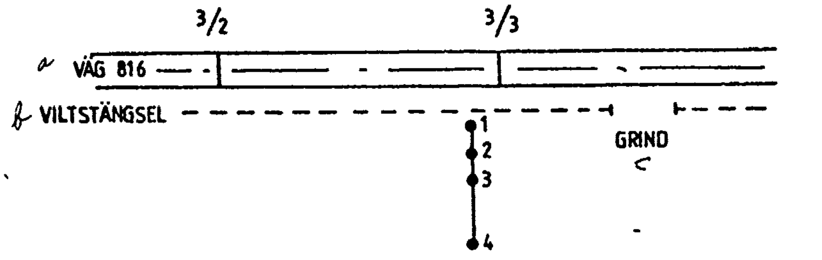


Fig. 11. Sketch of study site Sturup (No. 14). Road 816, Holmeja-Sturup.

Key: (a) road 816 (b) wild animal fence (c) gate

The soil consists of brown soil. The soil is covered with a thick layer of humus and debris.

The vegetation type is meadow. The field layer is quite sparse and is characterized by yellow dead nettle, Stellaria, Mercurialis, and Melica. The vegetation was analyzed in the spring of 1974 and 1976.

Analyses of the soil samples yielded the following results:

Measuring point	Lead (mg/kg)		Sodium (mg/kg)		Chloride (mg/kg)	
	1974	1975	1974	1975	1974	1975
1	16	36	18	43	6,2	35
2	17	38	14	22	7,1	6,9
3	23	76	11	32	5,5	19
4	24	31	16	16	4,9	15

The greatest changes were noted nearest the road, where <u>Poa nemoralis</u> increased and <u>Stellaria nemorum</u> decreased (Table 4).

2.2.11. Stöpen 1, Skaraborg province, district 11. Road 48, Skövde-Mariestad, section 3/600, ADT ca. 4000

The observation zone is located on the east slope of Billingen and covers both sides of the road. West of the road, the zone is relatively steep and located above a high cut. The bedrock, which lies close to the surface, is covered with a thin layer of moraine. East of the road, the zone is almost flat and lies below the road level. The soil depth is greater here and the moraine has a greater stone content. Possibly it can be considered a poorly assorted sediment (gravel, sand).

Eight measuring points were laid out, 4 on each side of the road (Fig. 12).

The vegetation consists of an oak-hazel forest with a species-rich field layer including, among others, <u>Viola canina</u>, two-leaved maianthemum, Mercurialis, <u>Dentaria bulbifera</u>, wood anemone, and blue anemone.

Tabell 4. Vegetationsanalys vid observationsområde Sturup (Analyses of vegetation at study site Sturup.)

LÄN M VÄG 816 PUNKT 1 — province M, road 816, point 1
ÅR 1974 VECKA 20 DAG 4 — 1974, week 20, day 4
KARTANGIVELSE 2021 0934 — map indication 2021 0934
BELÄGGSTATUS — overlay status
OMRÅDE 14 — district 14

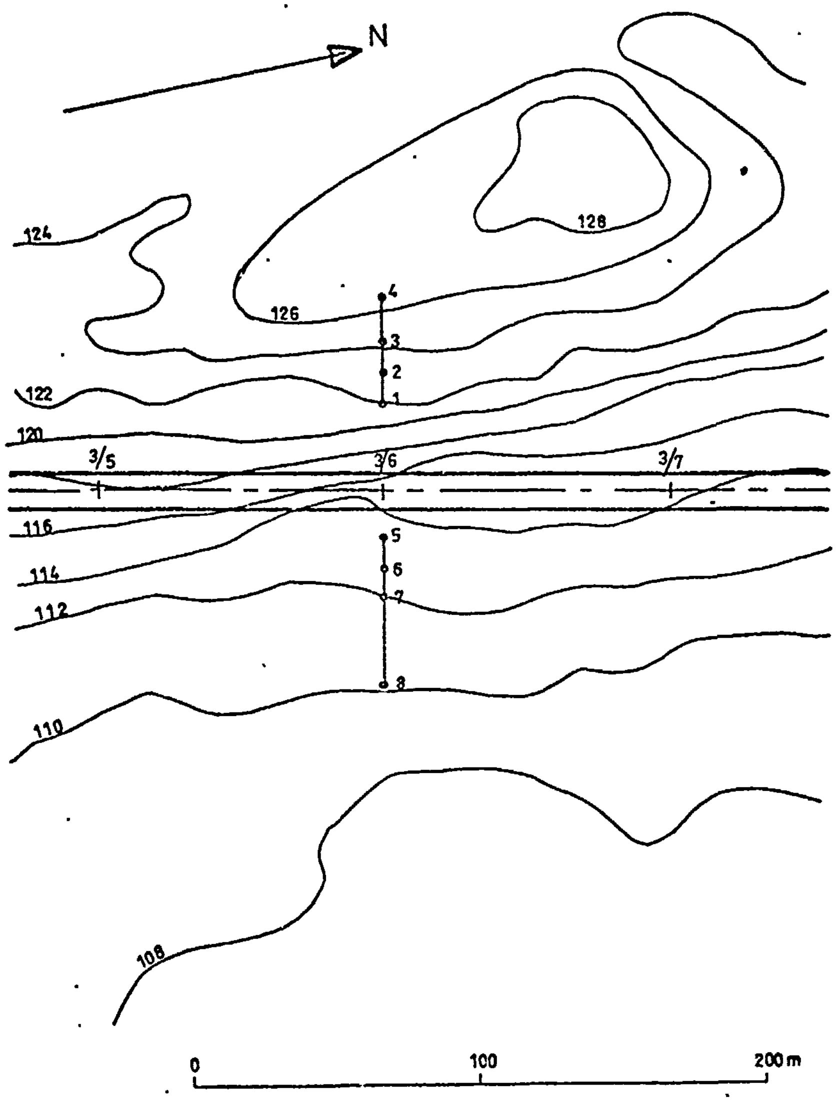
	1	2	3	4	F	C	M
ANEMONE NEMOROSA	30	30	10	5	100.	19.	18.8
FAGUS SILVATICA	50	60	70	60	100.	60.	60.0
STELLARIA NEMORUM	20	30	10	10	100.	17.	17.5
VIOLA CANINA	1	0	0	0	25.	1.	.3
MELICA NUTANS	1	1	1	0	75.	1.	.8
POA NEMORALIS	5	1	10	1	100.	4.	4.2
ANTAL ARTER PER RUTA (number of species per square)	6	5	5	4			

TOTALT ANTAL ARTER = 6 — total number of species

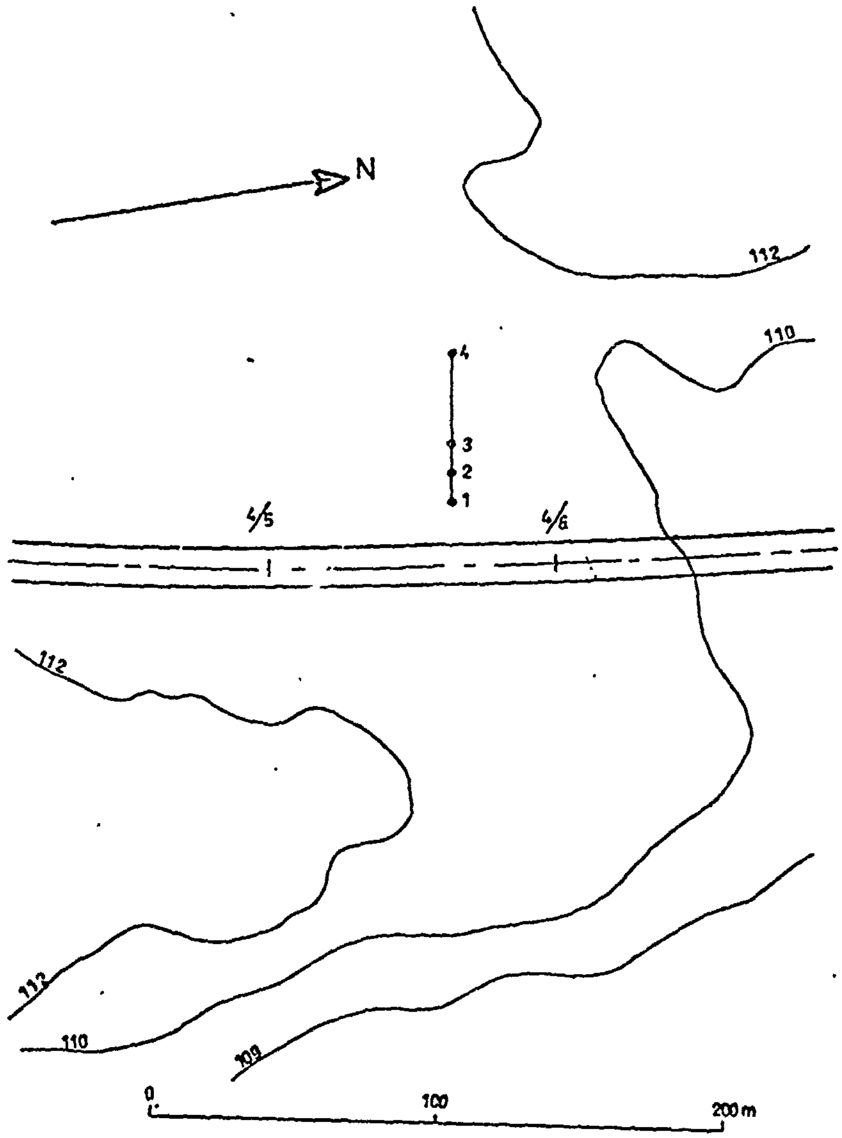
LÄN M VÄG 816 PUNKT 1 — province M, road 816, point 1
ÅR 1976 VECKA 23 DAG 2 — 1976, week 23, day 2
KARTANGIVELSE 2021 0934 — map indication
BELÄGGSTATUS — overlay status
OMRÅDE 114 — district 114

	1	2	3	4	F	C	M
ANEMONE NEMOROSA	70	40	20	10	100.	35.	35.0
EPILOBIUM ANGUSTIFOLIUM	0	2	0	0	25.	2.	.5
FAGUS SILVATICA	70	70	60	60	100.	65.	65.0
SORBUS AUCUPARIA	0	1	0	0	25.	1.	.3
STELLARIA NEMORUM	0	1	0	1	50.	1.	.5
VIOLA CANINA	1	1	0	1	75.	1.	.8
DACTYLIS GLOMERATA	0	2	0	0	25.	2.	.5
MELICA NUTANS	3	2	1	5	100.	3.	2.7
POA NEMORALIS	20	10	30	5	100.	16.	16.2
ANTAL ARTER PER RUTA (number of species per square)	5	9	4	6			

TOTALT ANTAL ARTER = 9 — total number of species



Figur 12. Observationsområde Stöpen 1 (nr 11). Rv 48, Skövde - Mariestad. (Study site Stöpen 1 (No 11). Road 48, Skövde - Mariestad).



Figur 13. Observationsområde Stöpen 2 (nr 12). Rv 48, Skövde - Mariestad. (Study site Stöpen 2 (No 12). Road 48, Skövde-Mariestad.)

Vegetation analyses were carried out in 1974 and 1976. The road was opened for traffic in the fall of 1973. Marked changes in the prevalence of the plants were observed primarily at measuring point 1 where an intense shrub growth was noted. This could have been due to root sprouting after clearing for the road right-of-way.

Soil samples were collected in the fall of 1973, immediately before the road was opened to traffic. The analyses yielded the following results:

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	7,6	16	3,6
2	7,8	19	21
3	9,1	26	8,9
4	8,0	20	7,8
5	9,7	19	6,7
6	9,9	21	13,3
7	9,7	32	8,9
8	7,5	24	8,5

2.2.12. <u>Stöpen 2, Skaraborg province, district 12. Road 48. Skövde-Mariestad, section 4/565, ADT 4000</u>

The observation zone lies west of the road and on a plane with it. Four measuring points were laid out along a line perpendicular to the road (Fig. 13).

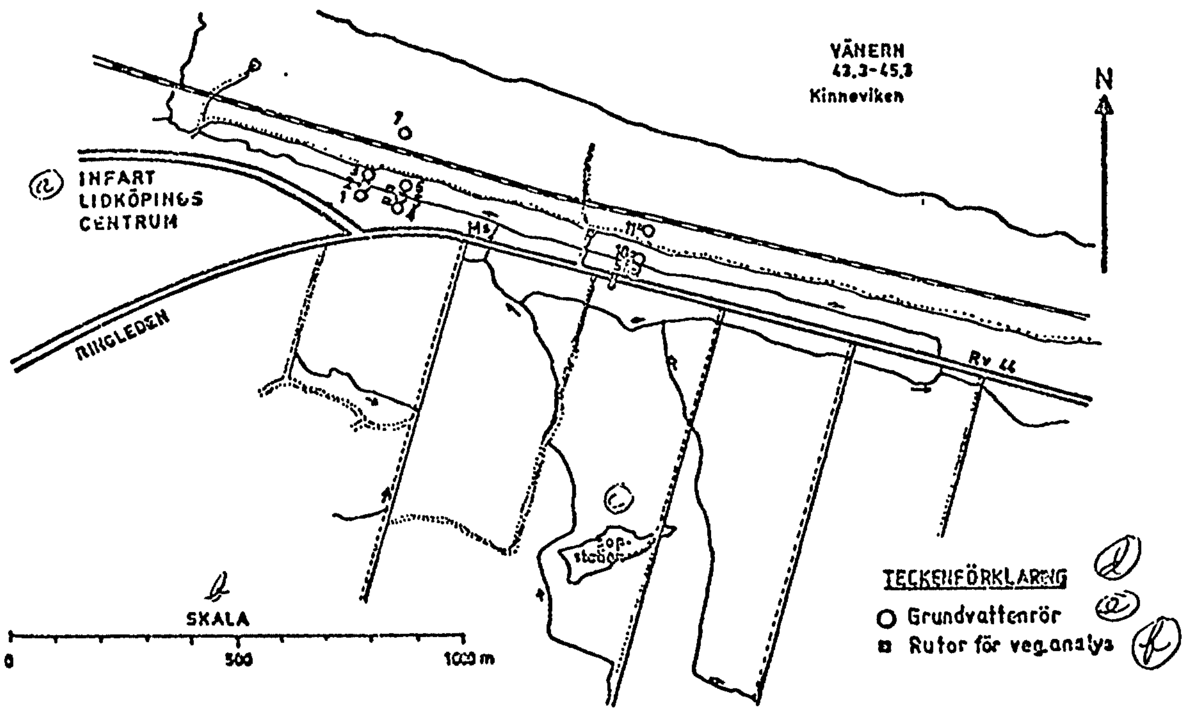
The soil type consists of a sandy moraine with a moderate stone content.

The area is covered with spruce forest of the lean type, where the field layer is dominated by curly grass with a moderate content of blueberries and lingon. The vegetation was analyzed in 1974 and 1976. On the latter occasion measuring point 1 had been damaged by a root puller. No appreciable changes in the vegetation occurred at the other measuring points. The results of the analyses of the soil samples collected in 1973 are given in the following Table:

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	49	74	71
2	27	89	66
3	47	61	104
4	17	57	28

Wall moss was also collected in the 1973 sampling. It was analyzed for heavy metals with the following results:

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
1	36	3,3	10
2	51	5,3	11
3	41	316	9
4	51	4,1	10



Figur 14. Observationsområde Lidköping (nr 28). Rv 44, Lidköping-Mariestad.

(Study site Lidköping (No 28). Road 44, Lidköping-Mariestad.)

Key: (a) entrance to downtown Lidköping (b) scale (c) central garbage-collection station (d) legend (e) ground water pipe (f) areas for vegetation analysis

2.2.13. Lidköping, Skaraborg province, district 28. Road 44, Lidköping-Mariestad (east of Lidköping), ADT 5750

Within the observation zone lying north of the road many conifers had died during recent years. This could undoubtedly be due to the high chloride content in the ground water (cf. Section 3.2.5).

The area is level, with a very high ground water level. The substratum consists of sand on clay.

The vegetation analyses were performed within six 10 x 10 m areas that were laid out in conjunction with the pipes for ground water observations that are being carried out within the zone (Fig. 14).

At points 1-4 the vegetation consists of a relatively dense spruce forest with moisture-requiring plants, e.g., May ferns, at points 5 and 6 of a more sparse, drier forest of pine and spruce.

2.2.14. Lindbäck, Gävleborg province, district 5-6. Road E4, Uppsala-Gävle, Mehedeby-Gävle portion, section 17/500-18/000, ADT 6700 (refers to old E4 north of Marma)

The observation zone is described in greater detail in Section 3.2.1. The location of the measuring points is indicated in Fig. 15.

The vegetation at points 5:1 and 5:2 consists of a moss-rich spruce forest, at point 5:3 of a wet spruce forest, where the proportion of marsh plants is significant. At point 6:1 the vegetation can be characterized as a leafy marsh growth and at point 6:2 as an extremely lean marsh that passes into a pine bog. Analysis of the vegetation was carried out in 1974 and 1976, i.e., before and after the road was finished on this stretch. However, the road was not opened to traffic until the fall of 1977. Pronounced changes in the plant prevalence were observed at point 6:1, where tall plants such as Filipendula ulmaria and Circium heterophyllum had increased their proportion.

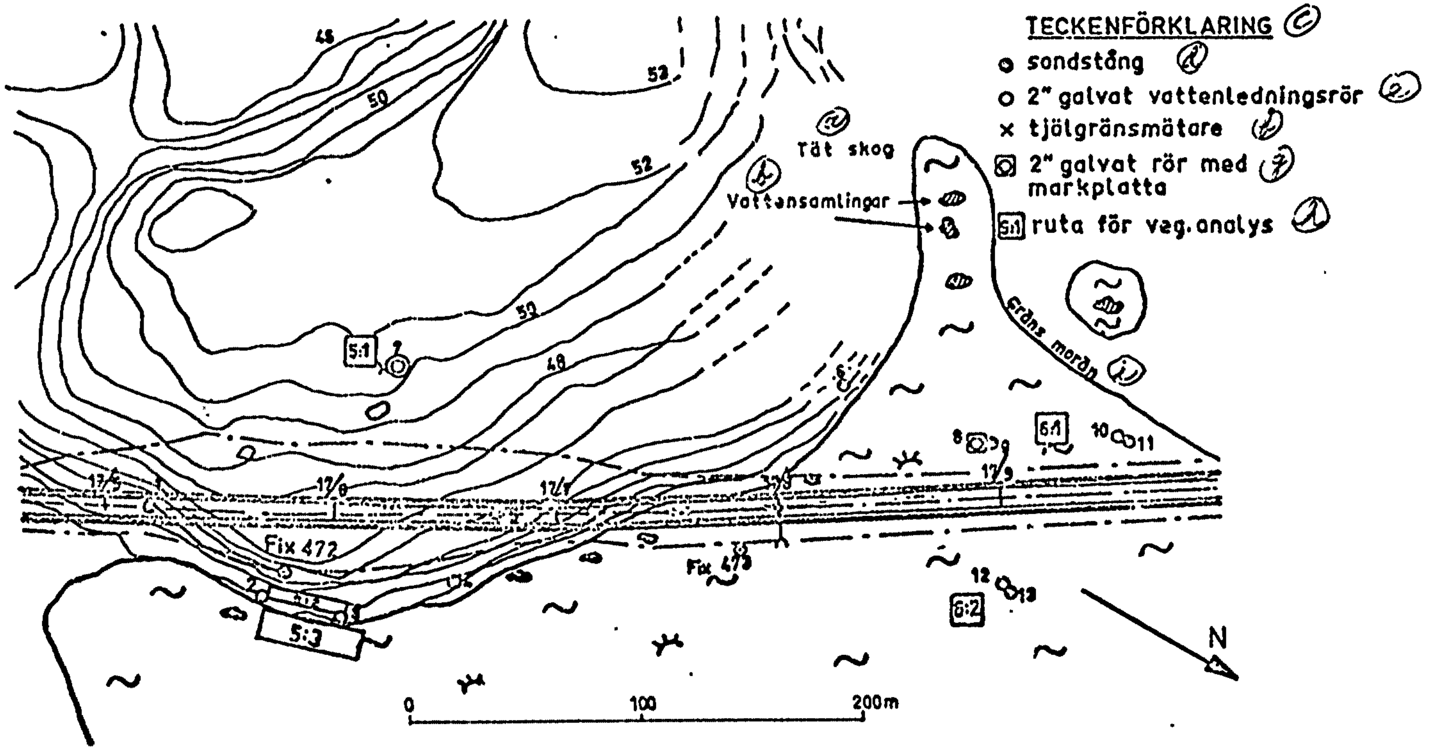
The results of the soil analyses in 1973 are given in the following Table.

Measuring point	Lead (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)
5:1	32	79	170
6:1	73	37	77

Wall moss (Hypnum) samples were collected in 1973 from 2 points and analyzed for heavy metals, with the following results.

Measuring point	Lead (mg/kg)	Nickel (mg/kg)	Vanadium (mg/kg)
5:1	49	7.3	18
6:1	33	5.7	9.1

2.2.15. Liden, Västernorrland province, district 18. Road 86, Sundsvall-Bispgården, Flygge-Liden-Oxsjöån portion, section 39/000-39/500, ADT 660



Figur 15. Observationsområde Lindbäck (nr 5-6). E4, Mehedeby-Gävle. (Study site Lindbäck (No 5-6). Road E4, Mehedeby-Gävle.)

Key: (a) dense forest (b) water accumulations (c) legend (d) sounding rod (e) 2" galvanized water pipe (f) frost-line measuring instrument (g) 2" galvanized pipe with ground plate (h) area for vegetation analysis (i) moraine boundary

The observation zone lies on a steep slope on both sides of the road right-of-way. Within this zone, 6 measuring points were laid out (Fig. 16). The soil type at points 1, 2, 3, and 6 consists of silty sediment on moraine and at points 4 and 5 of moraine without a sediment overburden. The hydrological and geological circumstances of the zone are described in more detail in Section 3.2.4.

The vegetation was studied inside of 10 x 10 m areas. Points 1 and 3 lie in a leaf marsh downstream from the road line. Points 2 and 6 lie in ravine formations downstream and are overgrown with meadow-like spruce forest, where Actaea spicata, Ribes, and Angelica silvestris, among others, can be observed in the field layer. Points 4 and 5 lie upstream from the road line and are overgrown with spruce forest of the moorland type. Vegetation analyses were carried out in 1974 and 1976, immediately prior to the beginning of excavation and after the road was opened to traffic. Point 1 was destroyed during the construction work. No changes could be detected at the other points during the study period.

2.2.16. Sollefteå, Västernorrland province, district 17. Road 90, Lunde-Sollefteå, Hällsjö-Multrå portion, section 8/300, ADT 2400

The observation zone lies on the side slope on both sides of the road, which obviously cuts off the natural water flow (Fig. 17). The substratum consists of a sandy moraine.

The vegetation was analyzed inside of two 10 x 10 m areas. It consists of a spruce forest, along with curly grass, two-leaved maianthemum, blueberry, and linnaea, among others, in the field layer. Upstream from the road there are some alders and midsummer flowers, which could indicate better water access there. There are several dead spruce downstream from the road. Vegetation analysis was carried out on only one occasion (in 1974), when the road had been in use for 10 years.

2.2.17. Steken, Jämtland province, district 4. Road 824, Ankarvattnet-Stekenjokk, section 25/290-25/340

The observation zone lies on a gentle upward slope south of the road. Twelve measuring points were laid out along 3 lines perpendicular to the road (Fig. 18).

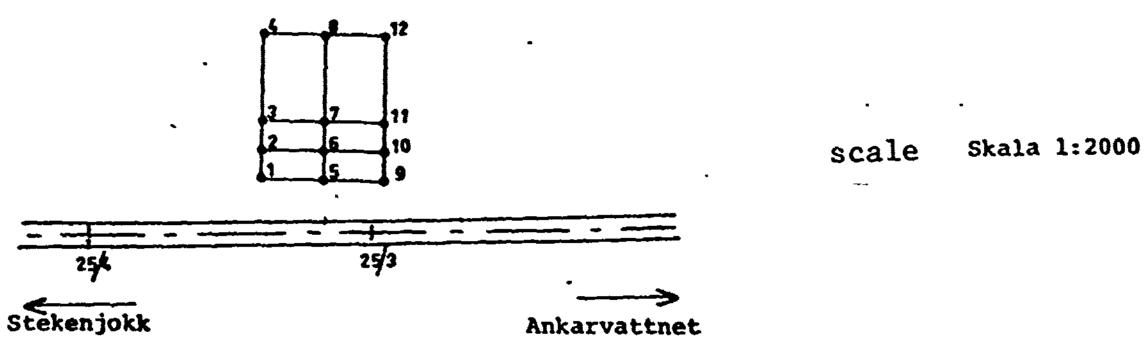
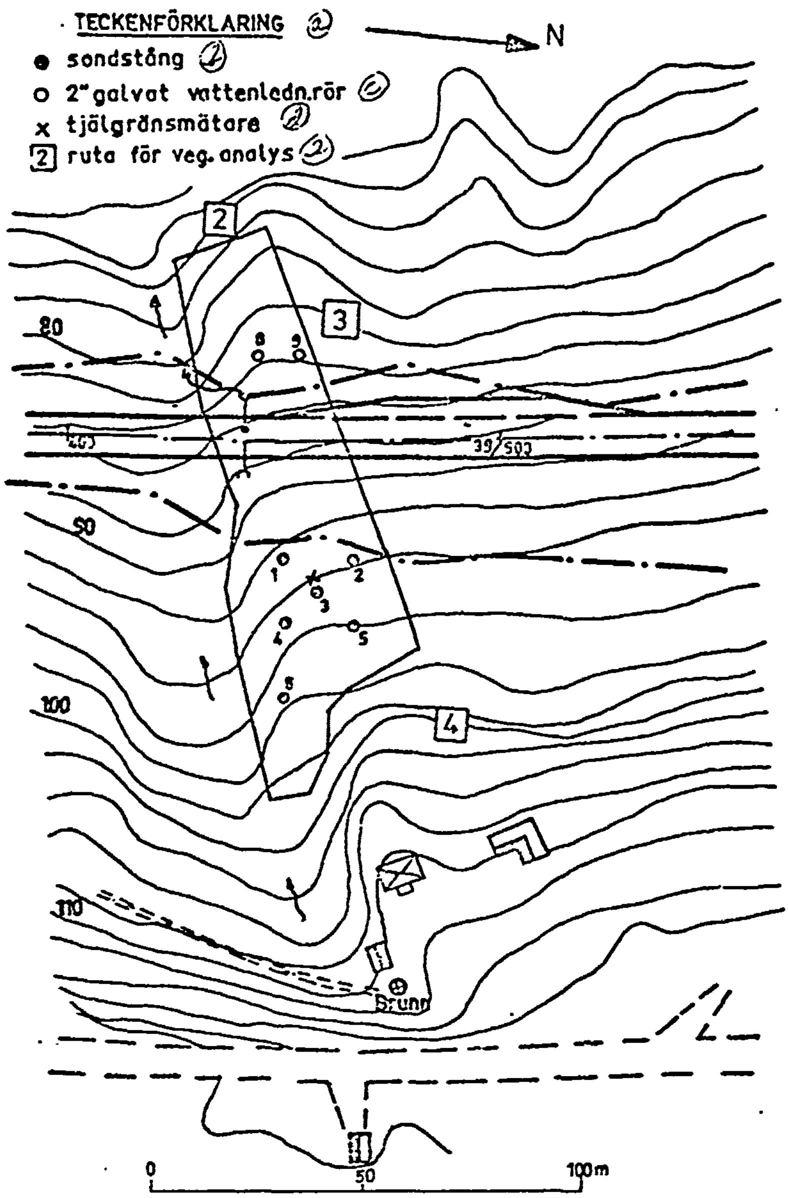
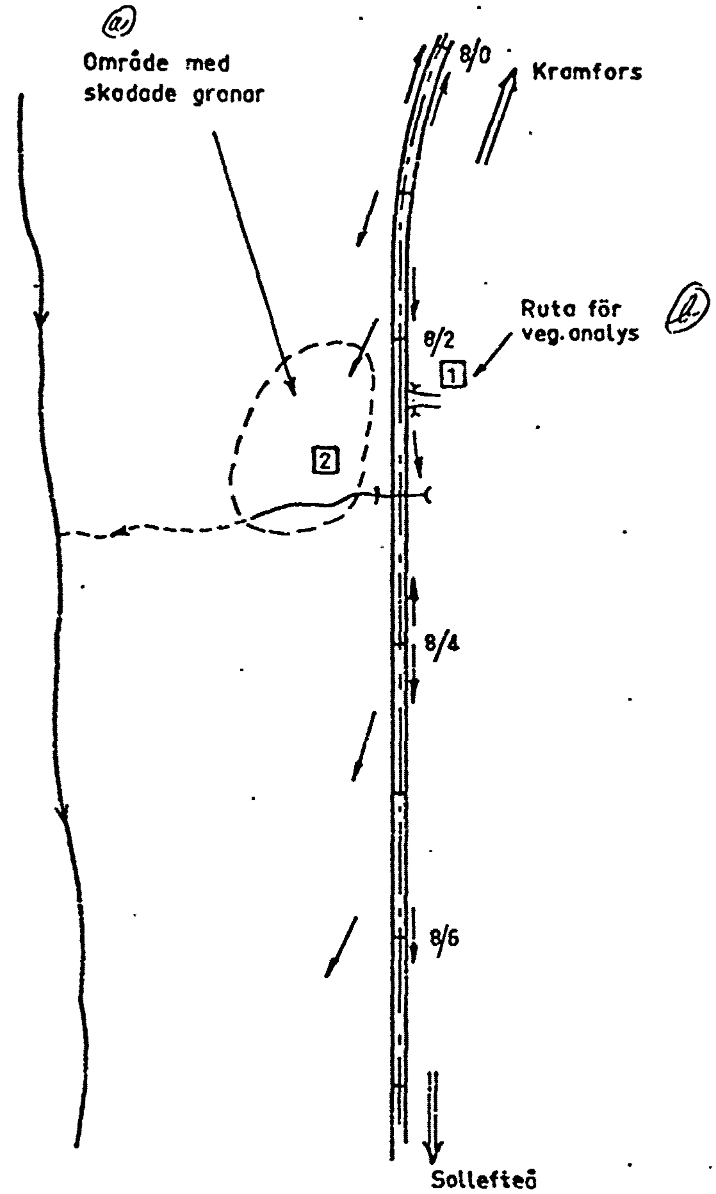


Fig. 18. Sketch of the Steken observation zone (No. 4). Road 824, Ankarvattnet - Stekenjokk.



Figur 16. Observationsområde Liden (nr 18). Rv 86, Sundsvall - Bispgården. (Study site Liden (No 18). Road 86, Sundsvall-Bispgården.)

Key: (a) Legend (b) sounding rod (c) 2" galvanized water pipe (d) frost-line measuring instrument (e) area for vegetation analysis



Figur 17. Skiss över observationsområde Sollefteå (nr 17). Rv 90, Lunde - Sollefteå. (Sketch of study site Sollefteå (No 17). Road 90, Lunde-Sollefteå.)

Key: (a) region with damaged spruces (b) area for vegetation analysis

The zone consists of a relatively flat surface cut through by several small stream beds. The soil type is a poorly classified sediment, primarily sand.

The vegetation consists of an alpine heath, where bushes and grass alternately predominate. The more important components are Empetrum nigrum, Calluna vulgaris, blueberry, curly grass, and Nardus stricta. The vegetation was analyzed on two occasions (1974 and 1976), when the road was opened to traffic.

Soil analyses were made in 1973 and 1975 and yielded the following results.

Measuring point	Lead (mg/kg)		Sodium (mg/kg)		Chloride (mg/kg)	
(mean value)	1973	1975	1973	1975	1973	1975
1, 5, 7	11.3	45	21.8	86	5.0	79
2, 6, 10	4.1	6.7	6.7	20	6.0	17.4
3, 7, 11	12.6	4.2	6.8	8	3.2	5.7
4, 8, 12	6.3	3.7	6.3	5.5	3.9	6

2.2.18. Stekenjokk, Västerbotten province, district 24-25. Road 1067, Lövliden-Stekenjokk, Klimpfjäll-Stekenjokk portion, section 16/300-17/100

The observations were made in areas east of the road that had been used as borrow pits during reconstruction of the road in 1974. The purpose of the studies was to determine how rapidly and with which species these surfaces that had been stripped of their vegetative cover and humus layer were recolonized.

The vegetation was studied on three 10 x 10 m test areas at the following locations.

Measuring point	24:1	24:2	25
Section	16/300	16/500	17/100

Point 24:1 was only ca. 10% overgrown with a total of 10 different species in 1975. The number of species was 21 in 1976 and 23 in 1977. It was primarily the grasses that increased with time, especially the Agrostis tenuis quantity (Table 5).

Point 24:2 was completely bare of vegetation in 1975, but by 1977 it was overgrown with grass.

The number of species at point 25 increased from 14 in 1975 to 28 in 1976 and 1977. The species present consisted primarily of grass and Cyperaceae. In the last analysis it was noted that primarily Agrostis tenuis, curly grass, and Festuca rubra had increased their presence (Table 6). Natural recolonization on the damaged surfaces had proceeded very slowly. This is due partly to the fact that the growth rate is low in the vegetation types involved, and partly, and perhaps most importantly, that melting water causes extensive erosion of the silty substratum. However, grass seeding appears to be capable to a great extent of preventing continuing erosion.

Tabell 5. Vegetationsanalys vid observationsområde Stekenjokk (nr 24). (Analyses of vegetation at study site Stekenjokk (No 24).)

LÄN AC VÄG 1067 PUNKT 1 — province AC, road 1067, point 1

KARTANGIVELSE 23E4H 4440 — map indication 23E4H 4440

OMRÅDE 24 — district 24

	DATUM		
	75384	76367	77406
ALCHEMILLA VULGARIS /COLL		1	1
CALTHA PALUSTRIS		1	1
CERASTIUM ALPINUM	1		
EPILOBIUM HORNEMANNI		1	1
RUMEX ACETOSA	1	1	1
SAGINA PROCUMBENS		2	2
SALIX HASTATA	5	4	10
SAXIFRAGA STELLARIS		1	1
AGROSTIS TENUIS		2	30
CAREX BIGELOWII	1	1	1
CAREX CANESCENS		1	1
DESCHAMPSIA CAESPITOSA	1	3	5
ERIOPHORUM SCHEUCHZERI		1	1
FESTUCA RUBRA			2
FESTUCA VIVIPARA			1
JUNCUS BIGLUMIS		1	2
JUNCUS FILIFORMIS		1	1
JUNCUS TRIGLUMIS	1		
LUZULA MULIFLORA SSP CONGESTUS		1	1
PHLEUM COMMUTATUM	1	1	5
POA ALPINA /COLL	1	1	2
EQUISETUM ARVENSE	1	2	2
BRYUM SP		10	10
PHILONOTIS SP		10	10
POLYTRICHUM PILIFERUM		1	1
MARCHANTIA POLYMORFA	1		
ANTAL ARTER (number of species)	10	21	23

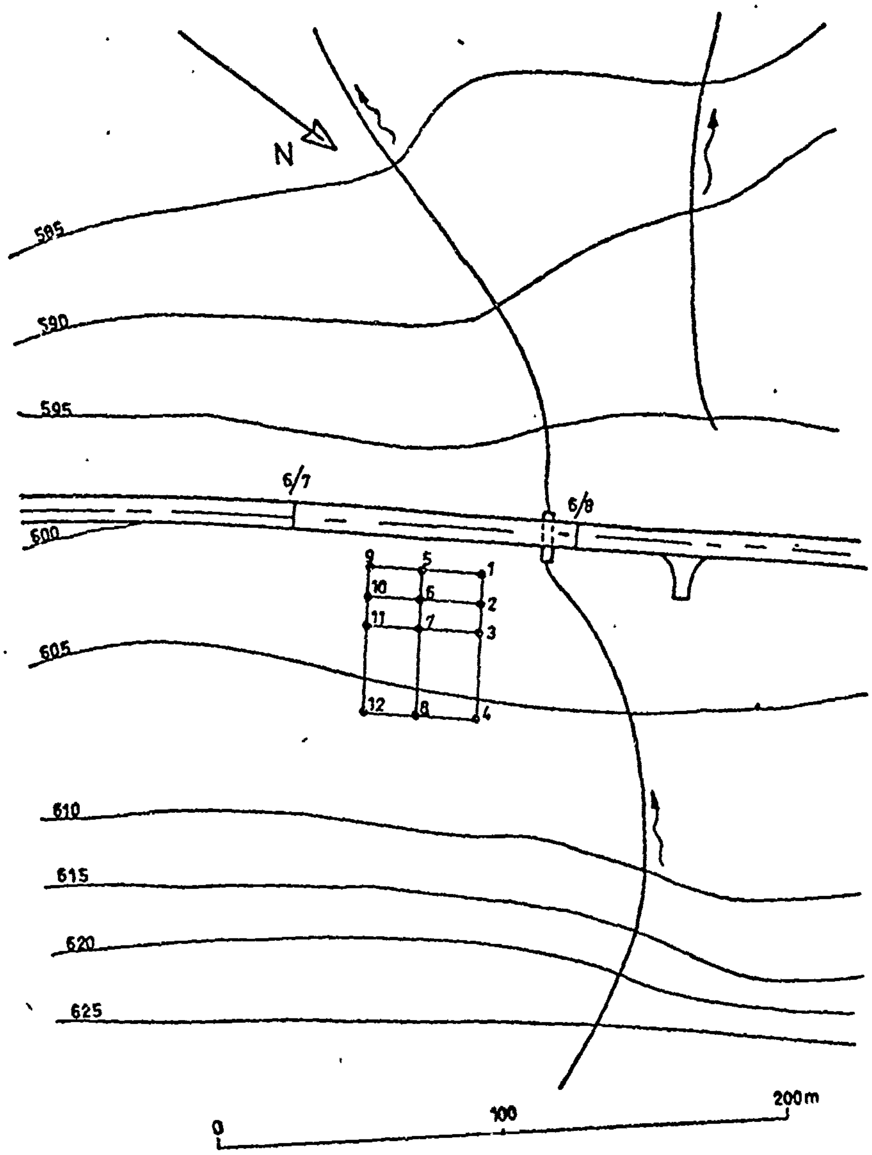
Tabell 6. Vegetationsanalys vid observationsområde Stekenjokk (nr 25). (Analyses of vegetation at study site Stekenjokk (Nc 25).)

LÄN AC VÄG 1067 — province AC, road 1067

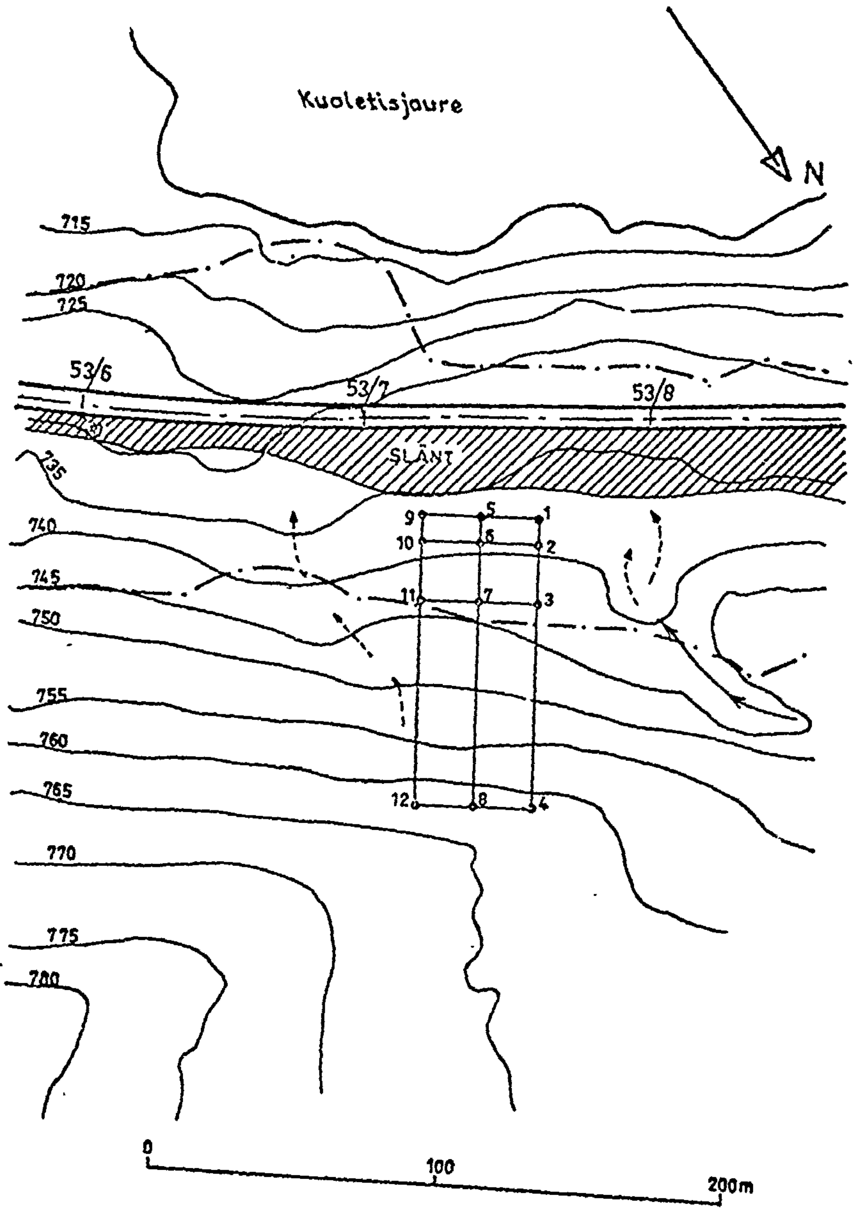
KARTANGIVELSE 23E4H 3834 — map indication 23E4H 3834

OMRÅDE 25 — district 25

	DATUM		
	75384	76367	77406
ARABIS ALPINA		1	1
CERASTIUM ALPINUM	1	1	1
EMPETRUM HERMAPHRODITUM	1	1	1
EPILOBIUM HORNEMANNI		1	1
HIERACIUM ALPINUM	1		
POLYGONUM VIVIPARUM		1	1
RUMEX ACETOSA		1	1
SAGINA PROCUMBENS		2	1
SALIX HASTATA	1	1	1
SAXIFRAGA STELLARIS		1	1
TARAXACUM VULGARIA /COLL		1	1
TUSSILAGO FARFARA	1	1	1
VERONICA ALPINA	1		
ALOPECURUS GENICULATUS	1		
AGROSTIS TENUIS		1	10
CAREX BIGELOWII	1	1	1
CAREX CANESCENS		1	1
DESCHAMPSIA CAESPITOSA	2	10	10
DESCHAMPSIA FLEXUOSA		1	5
FESTUCA RUBRA		1	10
FESTUCA VIVIPARA	1	1	1
JUNCUS BIGLUMIS		1	1
JUNCUS CASTANEUS		1	1
JUNCUS FILIFORMIS		1	1
JUNCUS TRIGLUMIS	1	3	2
LUZULA MULTIFLORA SSP CONGESTUS	1	2	2
PHLEUM COMMUTATUM	1	10	10
POA ALPINA /COLL	2	5	10
EQUISETUM ARVENSE		1	1
BRYUM SP		5	3
POLYTRICHUM PILIFERUM		2	2
ANTAL ARTER number of species	14	28	28



Figur 19. Observationsområde Saxån (nr 3). Väg 1067, Klimpfjäll - Stekenjokk. (Study site Saxån (No 3). Road 1067, Klimpfjäll - Stekenjokk).



Figur 20. Observationsområde Kuoletis (nr 1) Väg 622, Arjeplog - Graddis. (Study site Kuoletis (No 1). Road 622, Arjeplog-Graddis).

2.2.19. Saxån, Västerbotten province, district 3. Road 1067, Lövliden-Stekenjokk, Klimpfjäll-Stekenjokk portion, section 6/728-6/768

The observation zone lies on an upward slope north of the road (Fig. 19). Twelve measuring points were laid out along three lines from the road.

The soil cover in this zone is thin and consists of a sandy moraine. The zone is bounded on the north side by Beltonbäcken. Otherwise, there is no apparent surface drainage in the zone. The vegetation consists of an alpine birch forest, which for the most part is quite dry, and in the field layer is dominated by curly grass. The proportion of plants increases in the wetter portions, e.g., Circium heterophyllum, Mulgedium alpinum, Aconitum napellus, and Stellaria nemorum.

Vegetation analysis was carried out in 1974 and 1976, in both cases after the road had been opened to traffic.

The results of the soil analyses are given in the following Table.

Measuring point (mean value)	Lead (mg/kg) 1973	1975	Sodium (mg/kg) 1973	1975	Chloride (mg/kg) 1973	1975
1, 5, 9	6.7	6.7	12.0	11.5	92	14.5
2, 6, 10	4.6	4.6	9.3	10.5	26	12.0
3, 7, 11	9.3	8.5	22.0	21.0	93	28.0
4, 8, 12	10.0	8.7	16.0	14.0	15	17.0

2.2.20. Kuoletis, Norrbotten province, district 1. Road 622, Arjeplog-Graddis, Kuoletisjaure-Norwegian boundary portion, section 53/720-53/760, ADT 340

The observation zone lies on a moderate upward slope north of the road and above a cut covered with rip-rap of broken rock. Twelve measuring points were laid out within the zone (Fig. 20).

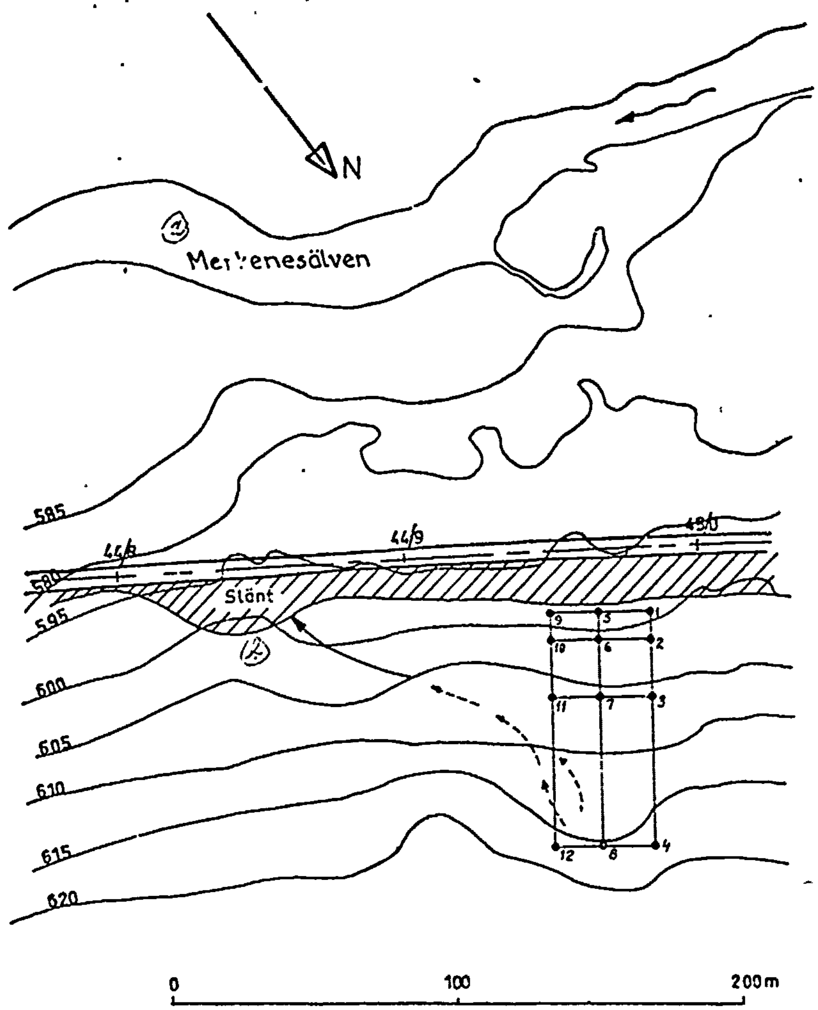
The bedrock, which consists of mica slate, is covered by only a thin layer of soil. Small flat surfaces with a thick peat cover (0.5 m) had formed here and there in pockets in the mountain.

Apart from a small brook northwest of the zone, it is drained primarily by runoff.

The vegetation consists of an alpine heath dominated by shrubs, e.g., Empetrum nigrum, Betula nana, blueberry, lingon, and Calluna vulgaris. The plants present included black hay, Pedicularis, golden rod, Arnica alpinum, and Cornus suecica.

The vegetation was analyzed in 1973, the year before the road was opened to traffic, and in 1976. No changes could be observed in the vegetation between the two points in time.

Soil sample analyses were carried out in 1973 and 1975 and yielded the following results:



Figur 21 . Observationsområde Merkenes (nr 2). Väg 622 Arjepleg - Graddis. (Study site Merkenes (No 2). Road 622, Arjeplog-Graddis.)
Key: (a) Merkenes river (b) slope

Measuring point (mean value)	Lead (mg/kg) 1973	1975	Sodium (mg/kg) 1973	1975	Chloride (mg/kg) 1973	1975
1, 5, 9	121	56	127	52	35	20
2, 6, 10	11	15	68	43	28	29
3, 7, 11	12	11	42	41	14	15
4, 8, 12	13	16	72	100	29	28

2.2.21. <u>Merkenes, Norrbotten province, district 2. Road 622, Arjeplog-Graddis, Merkenes-Kuoletisjaure portion, section 44/946-44/981, ADT 340</u>

The observation zone lies on the upstream side of the road in a relatively steep slope in the Merkenes river watershed. Twelve measuring points were laid out along 3 lines from the road (Fig. 21).

The soil type in the zone consists of a coarse moraine (sandy, gravelly). The soil depth appears to be relatively great. In the upper portion of the zone there is a marshy portion between two moraine ridges that is drained toward the southeast (Fig. 21). Otherwise, the zone lacks apparent drainage.

The vegetation consists of a plant-rich <u>Betula tortuosa</u> forest with a quite dense cover of birch and willow. <u>Filipendula ulmaria</u>, mid-summer flowers, Saussurea alpina, <u>Trollius europaeus</u>, alpine violet, <u>Mulgedium alpinum</u>, and golden rod.

The road was opened to traffic in 1972 and vegetation analyses were carried out in 1973 and 1976. No distinct trend in vegetation development can be observed between these two occasions.

The results of the soil analyses conducted are given in the following Table.

Measuring point (mean value)	Lead (mg/kg) 1973	1975	Sodium (mg/kg) 1973	1975	Chloride (mg/kg) 1973	1975
1, 5, 9	12	18	42	40	71	11
2, 6, 10	9.7	7.3	43	37	79	9.7
3, 7, 11	6.4	9.0	16	19	44	17
2, 8, 12	21	3.1	55	8	163	4.9

2.3. <u>Effects on the vegetation</u>

If the qualitative and quantitative composition of the flora is analyzed within a zone or study site on two separate occasions, different results are probably obtained. This difference can have several underlying causes; they are difficult to distinguish, but can be roughly classified on the following points.

- O measurement error
- O the flora is not in the same phenological state (annual development stage) on the observation occasions
- O a midyear variation occurs, caused primarily by climatic factors
- O a cyclic flora development occurs

- O the vegetation type enters a succession with a relatively rapid course, e.g., regrowth due to the cessation of cultivation
- O the vegetation develops in a definite direction due to altered environmental conditions, e.g., created by highway construction

In this study it is a vegetation development in accordance with the last point that is of interest to us, and which is designated here with the appelation "vegetation modification". In order to be able to observe such a modification during a brief observation period, it must of course be sufficiently great so that it predominates over the variations caused by other factors.

Usually, however, the vegetation modifications considered here are very slow processes; therefore, it is essential that as long a time as possible should elapse between the flora analyses within the same study site so as to increase the possibility of demonstrating modifications.

This project has run for only 4 budget years; consequently, only 2-3 years have elapsed as a rule between the periods of analysis. An attempt has been made to conduct the first analysis immediately prior to the beginning of construction. Inasmuch as this latter is governed in many cases by the prevailing labor market situation, the result is that the start of construction sometimes did not occur until one or two years after the initial analysis. In some cases the second analysis period was only a short time after the road had been completed. In other words, too short a time had elapsed in many instances, for a significant, observable vegetation modification, over and above the variations caused by other factors, to occur. This also applies to measurement errors.

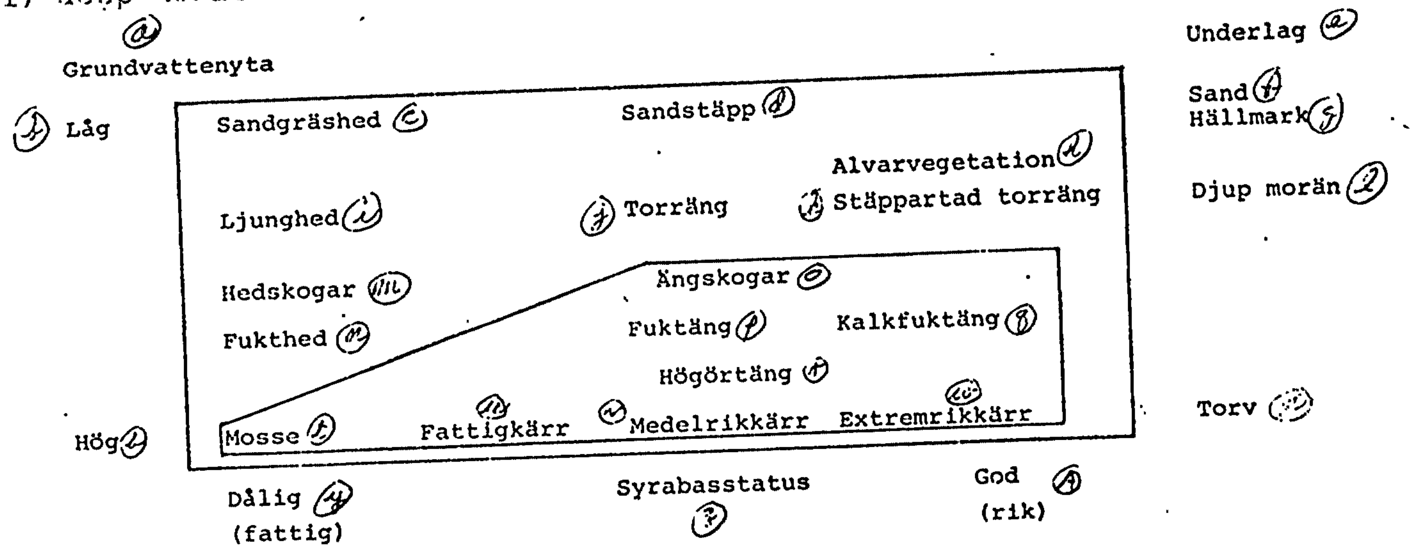
Because the two analysis periods could not be made to coincide with exactly the same phenological point in time, substantial differences in the degree of coverage frequently occurred, e.g., for spring plants. Such obvious circumstances are disregarded in the discussions on differences between the analysis periods. Care must also be taken with regard to evaluating the tree-layer cover, especially when the measurements are made inside of 1 m^2 squares. It is of course quite difficult to determine what portion of the tree crown cover lies directly above such a small test surface.

During the descriptions of the respective study sites (Section 2.2) the vegetation modifications observed were briefly mentioned. A thorough evaluation of the flora changes observed is made in the following section, with an attempt to ascertain the causes and classify them into different factors.

2.3.1. Effects of altered water access

An altered surface runoff (drainage) quite frequently occurs during road construction, and in some cases there is lowering of the ground water level over a more or less large area, the extent of which is dependent on the geological conditions. The opposite effect, damming, of course occurs also, but usually affects only small areas. Damming

Key: (a) ground water level (b) low (c) sand grass heath (d) sand steppe
(e) substratum (f) sand (g) thin soil layer over ledge (h) limestone soil vegetation (i) heather heath (j) dry meadow (k) steppe-like dry meadow
(l) deep moraine (m) heath forests (n) wet heath (o) meadow forests....



Figur 22. Schematisk översikt över vegetationstyper och sambandet med några viktiga miljöfaktorer. De typer som bedöms vara särskilt känsliga för vägdragningar har ramats in. (Scheme illustrating the connection between vegetation types and some important environmental factors. Types considered particularly sensitive to roads are framed.)

(p) wet meadow (q) wet lime meadow (r) high plant meadow (s) high
(t) peat bog (u) lean marsh (v) medium-rich marsh (w) extremely rich marsh
(x) peat (y) poor (lean) (z) acid-base status (A) good (rich)

is most frequently caused by the fact that dikes and drains do not perform their intended function or that an impervious road embankment was constructed. The effect on the vegetation obviously becomes quite extensive if, e.g., the ground water level rises above the ground surface.

In this study only insignificant areas that were subject to overdamming were observed. At Kvartinge the water level rose markedly within a few square meters next to the road. The vegetation there was modified such that Ranunculus flammula, swamp violet, peat mosses, and other marsh plants replaced the conifer species that grew there previously. This overdammed region is however not represented by any measuring points. The water level appears to have risen in the vicinity of the road drain at Potteboda also (Fig. 4), but changes were made there so that recently no effects on the flora were yet manifested and the surfaces that lie closest to the road and where changes should occur first were damaged.

The effects of reduced water access were noted in several cases, e.g., at Gundlatorp, Sturup, and Stöpen 1. Upon revisiting the study sites, changes in the composition of the vegetation could frequently be observed closest to the road, probably due to increased drainage. In the forested areas the increased introduction of light after the highway right-of-way was opened up certainly plays a major role due to the fact that water availability, at least in the soil surface, is reduced due to increased evaporation. The species that require moisture, e.g., hazel, blue and white anemones, Dentaria bulbifera, lower violet, Pulmonaria, and other so-called copse plants, may undergo a sharp diminution, especially above high cuts. An original meadow-type vegetation can thus develop in the direction of a heath type.

The flora types that can be expected to be particularly sensitive to road construction are thus those that are dependent on a high soil water content, which in turn is most frequently an effect of a high ground water level or runoff.

In order to provide a summary of the most important of the Swedish flora types, they have been classified into a scheme (Fig. 22) in accordance with two important environmental factors; a dry-wet gradient and an acid-base gradient. It can be stated in general that a vegetation type is more sensitive to water-level changes, the closer the water level is to the top of the ground, and the smaller the natural water-level variations. The vegetation types most readily affected by road construction are thus those that require moisture (in the lower part of the Figure). Special attention should be devoted to the more fertile of these types, inasmuch as they are less common in the country and are considered to be especially valuable from the environmental protection standpoint due to their species-richness and the presence of rare species. Thus, for example, extremely fertile marshes are particularly sensitive, especially since they are frequently located in a sloping area with moveable ground water that can be easily drained during highway construction. Among meadow-type forests elm, ash, and alder forests are particularly sensitive to reduced water availability, while meadow-oak, meadow-beech, and meadow-spruce forests should be somewhat more tolerant.

Although many moisture-requiring species decrease in prevalence in the immediate vicinity of the highway, species from plant communities on the edges of the road frequently penetrate in turn into this peripheral zone. This may involve species that frequently pertain to dry meadow vegetation or cultivated land, or species that originate from the grass-seed mixtures used for sowing the road slopes.

Especially in the case of alpine roads, this incursion of species foreign to the region that results from such sowing is striking. Evers et al. [10] and Wistrand [11] had studied the sowings more thoroughly for the road BD 622 (Arjeplog-Graddis), for which studies were also conducted within the frame of this project. They found that sowings made with a mixture of Festuca rubra, meadow grass, Agrostis tenuis, and timothy develop toward a quite stable Festuca rubra community.

2.3.2. Mechanical effects of road construction

Mechanical effects on the vegetation caused by road construction have been observed primarily as wear and tear along the highway sections that run on bare mountainsides. Damage has occurred in regions where material and vehicles have been parked, where vehicles have been driven, and where borrow pits have been established. Even moderate wear can soon result in the zones becoming almost completely bare of vegetation as eyesores in the open alpine landscape.

The areas that are damaged are recolonized very slowly due to the slow rate of regrowth in mountain regions. The extensive soil erosion caused by the melting water also presents a hindrance to colonization.

Mechanical effects of road construction have also been appreciable in wetlands of various types, from quagmired forest land to peat bogs. This partly involves the driving tracks from the work vehicles and partly the piling of excavation material on large areas along the road. The vehicular tracks act as drainage ditches, while the frequently compact excavation masses form dams for the water flow in wetlands.

2.3.3. Effects of pollutants

The dispersion of heavy metals from the highway to the environment was studied during the first year of the project. For this purpose, moss samples were collected in some forested areas for analysis of lead, nickel, and vanadium. Soil samples were also collected in most of the study sites for analysis of chloride, sodium, and lead. Due to a change in direction for the project, these aspects could not be followed completely. Thus, moss samples were analyzed only in 1973 and no soil samples were analyzed after 1975. As a result, only the first-time measurements are available from many observation zones. For the sites where repeated analysis was possible, in turn, the time that elapsed between the analyses was generally so brief that it was impossible to detect any significant changes.

One study site, No. 28 at Lidköping, was laid out because salt damage was suspected there. Within the zone a large portion of the conifers (ca. 60%) had died within a broad area along the highway. The chloride measurements in the ground water show that the concentra-

tions generally range between 200 and 300 mg/liter. The origin of the salt in this zone is discussed in Section 3.2.5.

3.3.4. General information on salt damage and lead pollutants

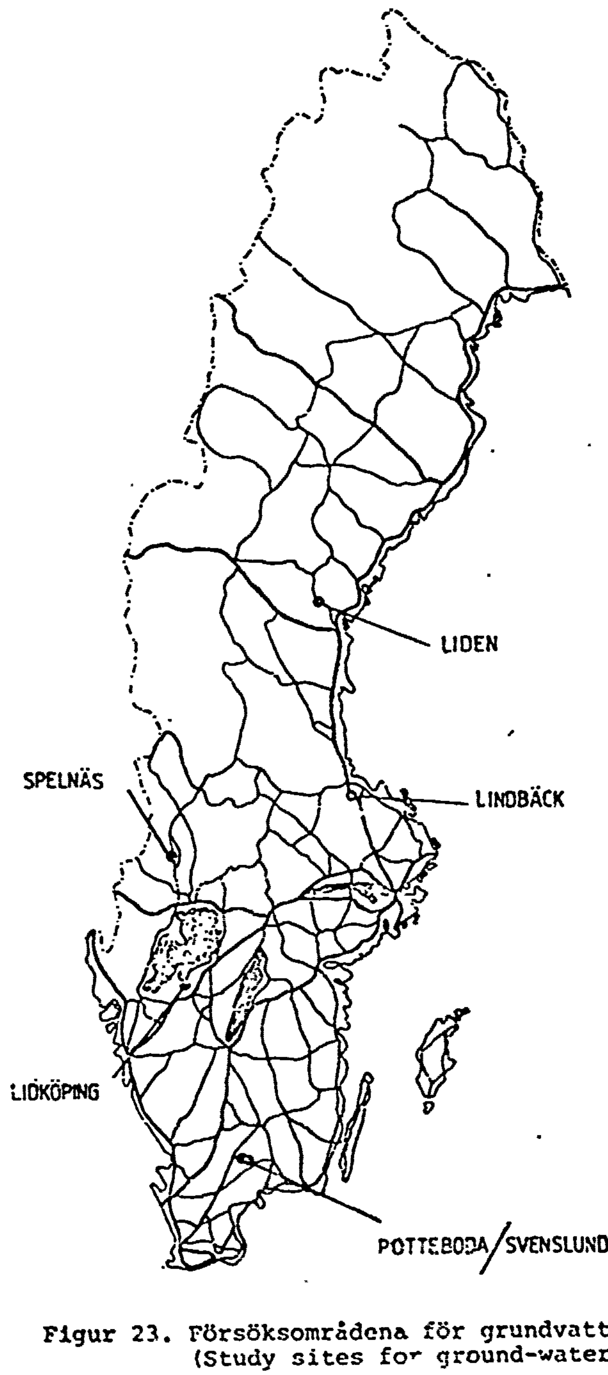
Within the project a literature study on the effects of salt and heavy metals, especially lead, was presented previously [12]. Since then, the already abundant literature on salt damage has been expanded by a number of papers. However, they generally describe only the damage observed in different areas and seldom contain basically new information. A quite condensed summary of the effects of salt and lead on soil and vegetation is given in the following.

The colloidal status of the soil is affected by sodium such that the colloids are dispersed when the Na concentration exceeds ca. 15% of the cation-exchange capacity. A structural change then occurs in the soil, which leads to a slower water transport, whereby the availability of both water and mineral nutrients is reduced.

The salt uptake by the plants can take place through both the roots and the above-ground parts. The roots of plants have a relatively effective barrier to sodium uptake via the roots, as a result of which chloride is generally accumulated more intensively in the leaf than sodium. Signs of damage are manifested as a gradual dying of the leaf from the edge toward the center. There are great differences between the salt resistance of the various species. Most annuals are more salt-tolerant than perennials, in whose roots sodium accumulates over the years. Due to the fact that chloride accumulates in the leaves of deciduous trees, a large portion of the chloride taken up is eliminated when the leaves fall, which explains why evergreens are considerably more salt-sensitive than deciduous trees. Salt damage on trees is generally limited to a distance of less than ca. 20 meters from the highway, and it is primarily conifers that are affected. This means that the risk of forest damage along newly constructed highways with berms, ditches, and cleared road slopes, etc. is not as great as along older roads, where the forest frequently grows right up to the road. The more extensive damage that is reported in foreign studies most likely can be explained by the substantially larger amounts of salt that are used there.

Pb contents in soil and plants were previously treated in a number of papers (see Refs. 12 and 13 and the literature cited there). Studies conducted domestically [14] reveal that substantially increased Pb levels (10-50 times the base values) can be detected up to ca. 150 meters from major trunk lines.

Lead halides are formed in the combustion of leaded gasoline, and they are converted into oxides and carbonates in the atmosphere. Lead pollutants that are transported into the soil are deposited in a very difficultly soluble form and an uptake through the roots is of very little significance. Most of the lead that directly involves the plants is deposited on the surface and only a minor proportion is transported into the tissues. The effect of lead on the flora and the decomposition of organic material has been studied primarily in laboratory tests. Increased Pb contents have been shown to inhibit



Figur 23. Försöksområdena för grundvattenundersökningar.
(Study sites for ground-water investigations.)

growth, chlorophyll synthesis, photosynthesis, respiration, transpiration, carbon dioxide exchange, and the function of the openings between two cells in the plant epithelium [13]. The microbiological activity of the soil is also adversely affected by lead [15].

2.4. Summarizing viewpoints

The changes in the vegetation as a result of highway construction could be observed in only a small number of study sites. However, this does not mean that in time, changes thatcan make themselves felt in other areas do not also occur. Available documentation of flora composition and the chemical conditions of the soil can thus perhaps acquire its maximum value as a basis for a study repeated after a number of years. Such a study is facilitated by a thorough description of the study sites and a uniform recording of all the vegetation data material in accordance with the RUBIN system on magnetic tape.

3. GROUND WATER

The purpose of the studies was to answer the following basic questions:

1. What hydrogeological changes can be expected in connection with roads constructed and established in undisturbed nature?

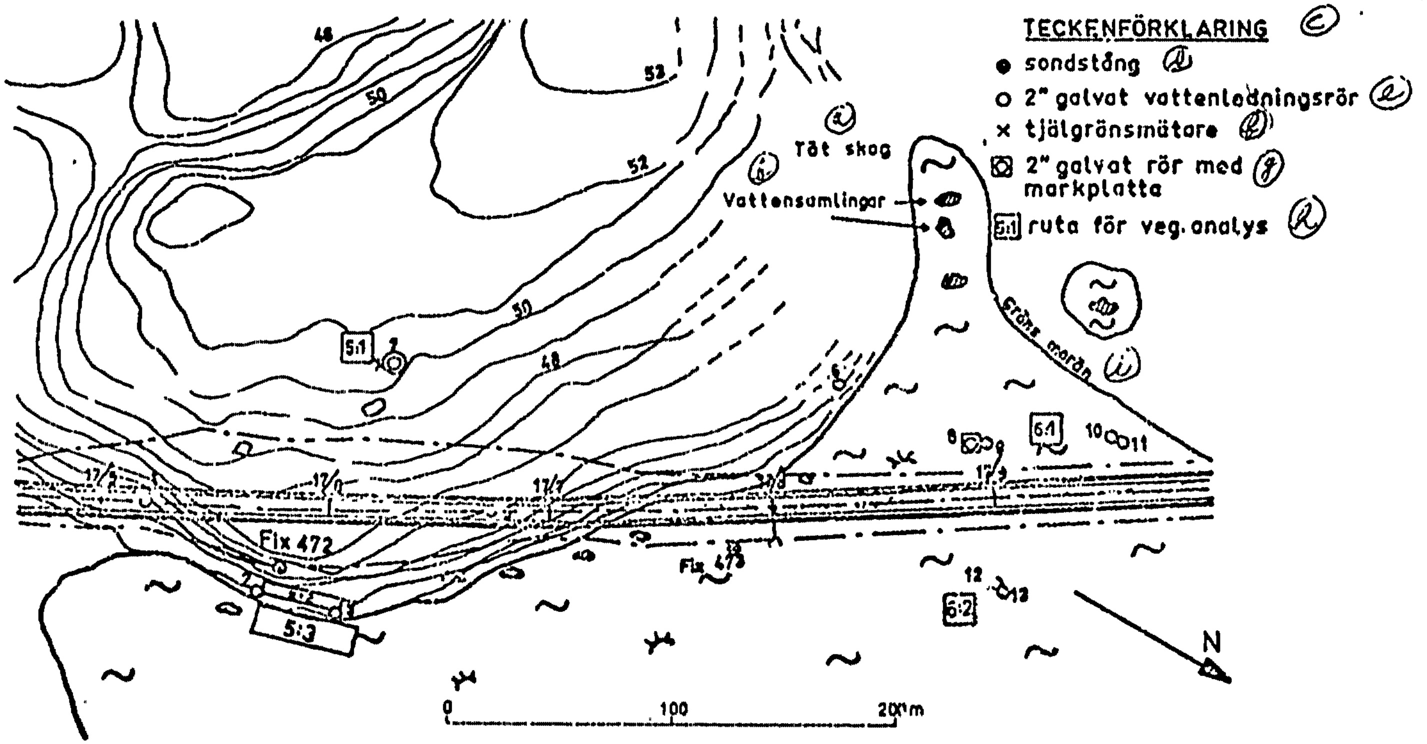
2. What natural types and terrain features can be considered particularly sensitive to such changes?

3.1. Investigation methods

In order to study how road construction, maintenance, and traffic affect the ground water conditions, 5 test sites were established in various hydrogeological media (Fig. 23). The test sites were selected with a view to the presence of pits and excavations that could affect the ground water in the surrounding region, and to the actual schedule of the highway project. The point in time for the excavation work primarily guided the choice of the test sites. All the sites except one (Lidköping) were thus localized by roads where the excavation work was imminently to begin.

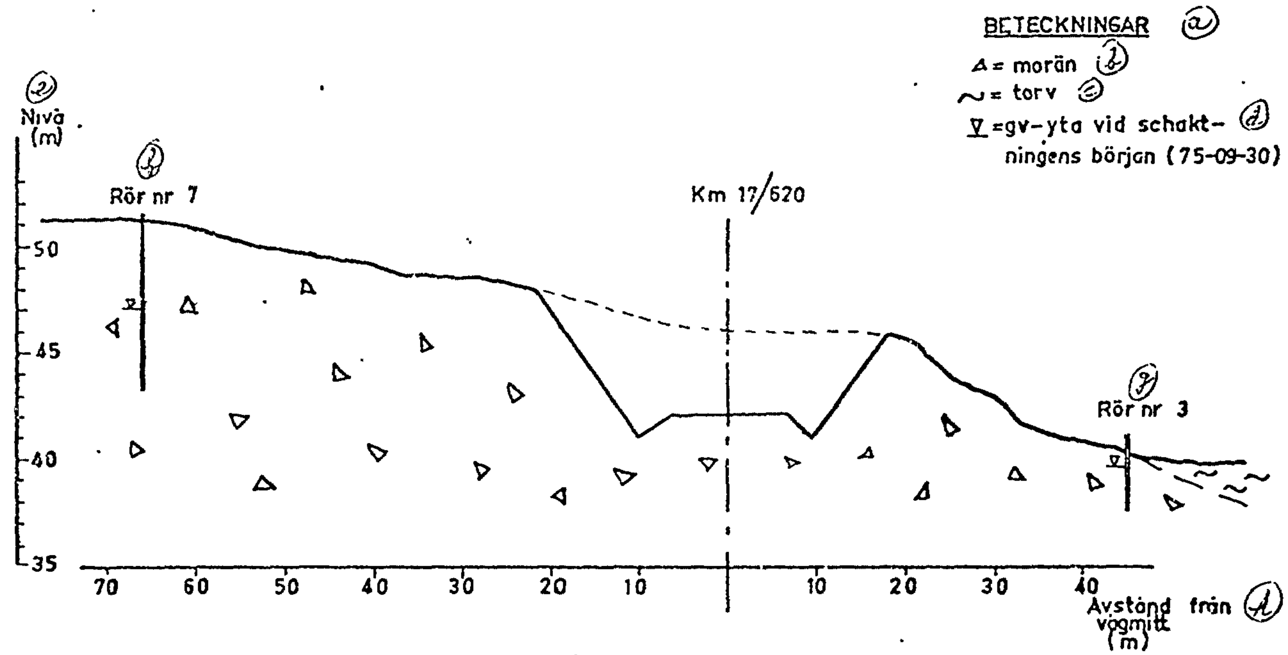
The ground water conditions were studied at the sites before, during, and after road construction through measurements of the level and the taking of ground water samples. Vegetation analysis and soil sampling were usually also carried out. The ground water level measurements were continued for approximately 1 year after the excavation work had been completed. The ground water sampling and vegetation analysis were generally repeated as late as possible in the schedule of the project, so that possible changes could be manifested.

In order to be able to establish the long-term effects from road maintenance and traffic, the studies had to be followed up with several samplings of soil and ground water. In order to establish the connection between drainage/damming and the changes in the flora at sight, the ground water level measurements must also be continued for a longer



Figur 24. Försöksområde Lindbäck. E4, Mehedeby-Gävle. (The study site Lindbäck. Road E4, Mehedeby-Gävle.)

Key: (a) dense forest (b) water accumulations (c) legend (d) sounding rod (e) 2" galvanized water pipe (f) frost-line measuring gauge (g) 2" galvanized pipe with soil-level indicator (h) areas for vegetation analysis (i) moraine boundary



Figur 25. Tvärprofil genom försöksområdet Lindbäck. (Cross-section at the study site Lindbäck.)

Key: (a) symbols (b) moraine (c) peat (d) ground water level at the beginning of excavation (e) level (m) (f) pipe No. 7 (g) pipe No. 3 (h) distance from center of road (in m)

period of time.

3.2. Test sites for hydrogeological studies

3.2.1. Lindbäck, road E4, Uppsala-Gävle

3.2.1.1. Description of the region

Road E4 between Mehedeby and Gävle was constructed in 1975-77 in a completely new, ca. 30 km stretch. The new highway (motor traffic artery) runs west of the old road through a relatively extensive forest region previously undisturbed by major highways. The topography along the stretch is low-rolling, generally with low moraine ridges alternating with swampy areas. The mean annual 24-hour traffic on the old road was ca. 7000 vehicles/24 hours in 1975.

The test site selected consists partly of a moraine ridge and partly of a swampy area (Fig. 24). A relatively deep excavation (6-7 m) was made in the moraine ridge (Fig. 25). The swamp was dug out to a solid bottom (max. 3 m) and refilled with moraine material. The excavation work was carried out during Oct.-Nov. 1975. The road was opened for traffic in November 1977.

The moraine ridge has in the surface a very high stone and boulder content as a result of an intense upheaval. The moraine material was affected by the upheaval to a depth of ca. 1 m. Below that point, the material consists of a hard-packed sandy, gravelly moraine. Large isolated boulders are present down to a depth of 6-7 m. Superficial clay layers were encountered at a couple of sites both during the preliminary study of the road project and during monitoring of the excavation work. In addition, a ca. 10 cm-thick layer of clay was encountered in the northern part of the ridge, ca. 5 m below the original soil surface. The location of this layer indicates that the moraine ridge was formed or effected through folding by the inland ice. This would also indicate that there are no thick cohesive clay layers in the moraine ridge.

The ground-water-bearing layer was encountered relatively close to the surface in the southern part of the ridge. This is apparently intimately bound with some "local" clay layer. Furthermore, the ground water level in the moraine ridge is quite deep. The ground water flows in a northeasterly direction out into the surrounding swampy region.

The swampy region consists partly of a lean marsh north of the ridge and partly of a pine peat east of the road line. The layer sequence in the marsh and peat bog is peat-silt-moraine and peat-muddy clay-moraine, respectively.

The excavation work was carried out in the region during the fall of 1975 (October-November). The marsh was dug out to the underlying moraine and refilled with moraine material from the ridge. The marsh was dug out with dredging machines. The excavated masses from the marsh were deposited on both sides of the road. The excavation and transport of the moraine material from the ridge was initially

done with crawler tractors. When the transport distance increased and the excavatability of the moraine material decreased, excavators and dump trucks were used to remove the moraine masses.

3.2.1.2. Measurements performed

The region was reconnoitered in the fall of 1973 and found to be suitable for hydrogeological studies. During the summer of 1974 pipes were placed for measurement of the ground water levels and the taking of samples in the moraine ridge and in the marsh. Due to the high stone and boulder contents, which made the pipe driving very difficult and time-consuming, only one ground water pipe was placed in the moraine ridge west of the road line (pipe No. 7). However, several pipes could be driven in the slope down to the marsh, some in the road line and some in the edge between the marsh and the moraine ridge (Fig. 24).

Pipe were placed in the marshy region at 3 points, two points in the marsh and one in the peat bog. Two pipes were positioned at each point, one pipe with perforations in the underlying moraine and one pipe with perforations in the peat ground, 0.5-1 m below the ground surface. A soil-level indicator for recording possible height variations in the marsh was placed in one of the pipes in the marsh.

Measurements of the ground water level were performed continuously (once or twice a month) from the summer of 1974 to the fall of 1977. Sampling and analysis of the ground water were carried out once or twice a year. The samples were analyzed for sodium and chloride contents.

3.2.1.3. Results

The results of the level measurements are given in Fig. 26. A drop in the ground water level in connection with the excavations was noted only in pipe No. 2. The drop (ca. 0.5 m) is permanent.

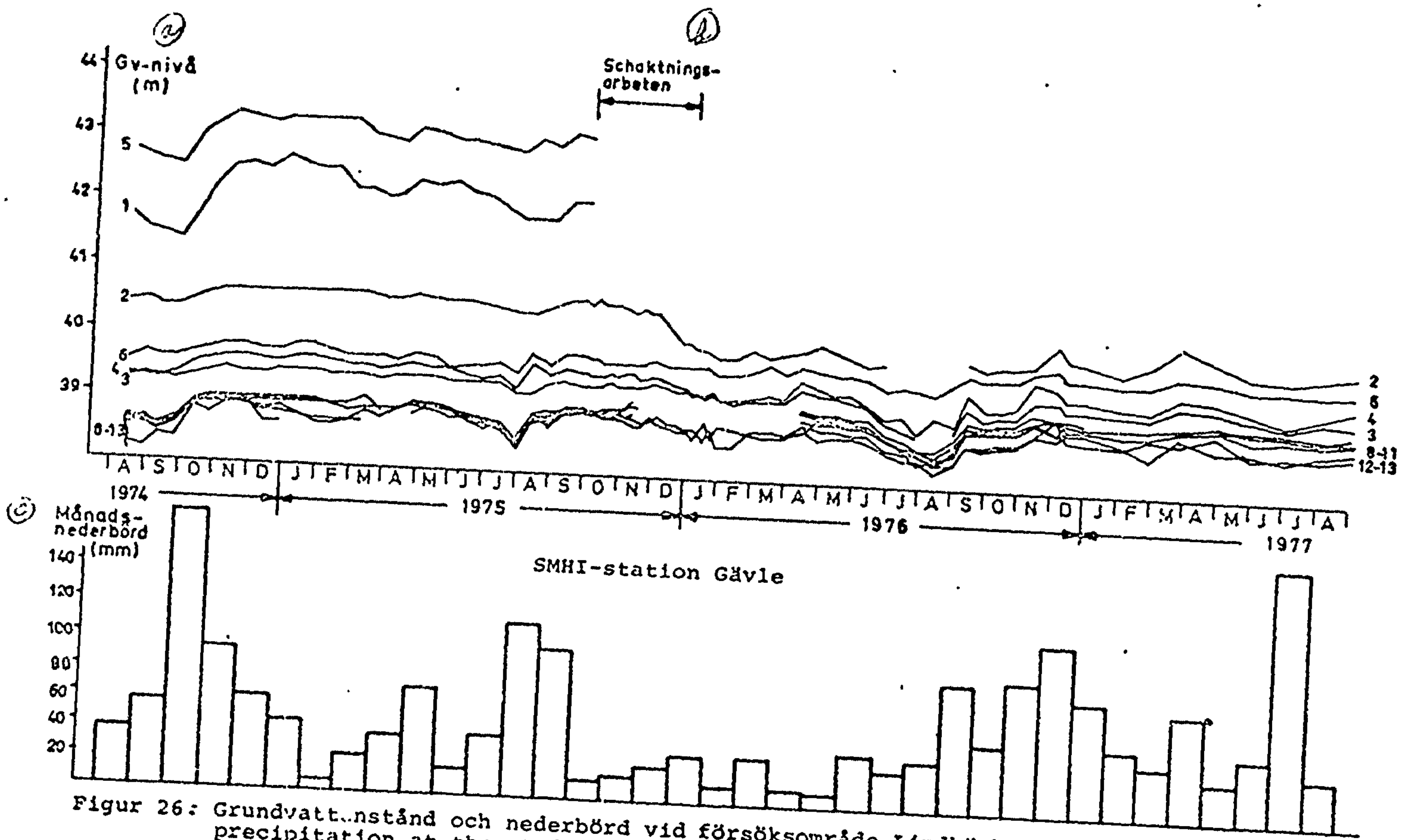
In connection with excavation of the marsh, some damming occurred west of the road. Thus, in 1976 and 1977 the water level in this zone (pipes Nos. 8-11) was 2-3 dm above the level on the east side (pipes Nos. 12-13). The precipitation data indicated in Fig. 26 were obtained from the SMHI station in Gävle.

No variations in height in the marsh could be detected with the soil-level indicator.

The results of the samplings and analyses effected on the ground water are contained in Table 7.

3.2.1.4. Conclusions

Superficial clay layers were encountered, as described above, at several sites in the excavation. The drop in the ground water level, as ascertained in pipe No. 2, is most likely due to the fact that a similar clay layer was cut and a secondary ground water level was thus drained, which certainly did not cover a great area. In addition, the ground water level in the moraine ridge is relatively



Figur 26: Grundvattenstånd och nederbörd vid försöksområde Lindbäck. (Groundwater level and precipitation at the study site Lindbäck.)

Key: (a) ground water level (b) excavation work (c) monthly precipitation (mm)

Tabell 7. Natrium- och kloridinnehåll i grundvattenprov från försöksområdet Lindbäck. (Contents of sodium and chloride in groundwater samples from the study site Lindbäck.)

(a) Rör nr	(b) Natrium (mg/l)			(f) Klorid (mg/l)		
	okt-74 (c)	nov-75 (d)	juli-77 (e)	okt-74 (c)	nov-75 (d)	juli-77 (e)
2	2,2	2,3	torr (g)	1,5	1,5	torr (g)
3	2,5	2,4	3,1	1,9	1,9	6,4
7	3,1	5,5	6,9	1,6	3,7	2,8
8	2,9	3,6	4,3	1,6	3,8	1,6
10	4,4	2,7	3,4	2,3	2,8	2,8

Key: (a) Pipe No. (b) sodium (c) Oct. (d) Nov. (e) July (f) chloride (g) dry

deep and no drop in connection with the excavation work could be noted. The large excavation thus had only a local, moderate effect on the ground water conditions, which in turn can cause local changes in the flora.

The rise in the water level that occurred in some parts of the marshy area is due to the fact that the tight fill material in the road bed dams up the water flow that comes from the moraine region in the west. This damming alters the conditions for the vegetation. Because this portion of the marsh region consists of swamp, the changes are apparently not so great as they would be if they involved the pine peat east of the road.

There are culverts through the roadbed in the sections 17/800 and 18/060, i.e., in the south and north portions of the marshy area. However, the most water-rich zone is found in the "bay" located at a level with the pipes Nos. 8 and 9, i.e., midway between the culverts (Fig. 24).

Since the marsh was excavated with a dredging machine, the material was placed in the immediate vicinity of the road. Thus, the material affects only a small portion of the environment (cf. Potteboda/Svenslund, p. 70).

The sodium and chloride contents measured in the ground water are quite low. The region is therefore quite suitable for monitoring the effect of road salt on an undisturbed natural environment.

3.2.2. Potteboda/Svenslund, road 120, Älmhult-Tingsryd

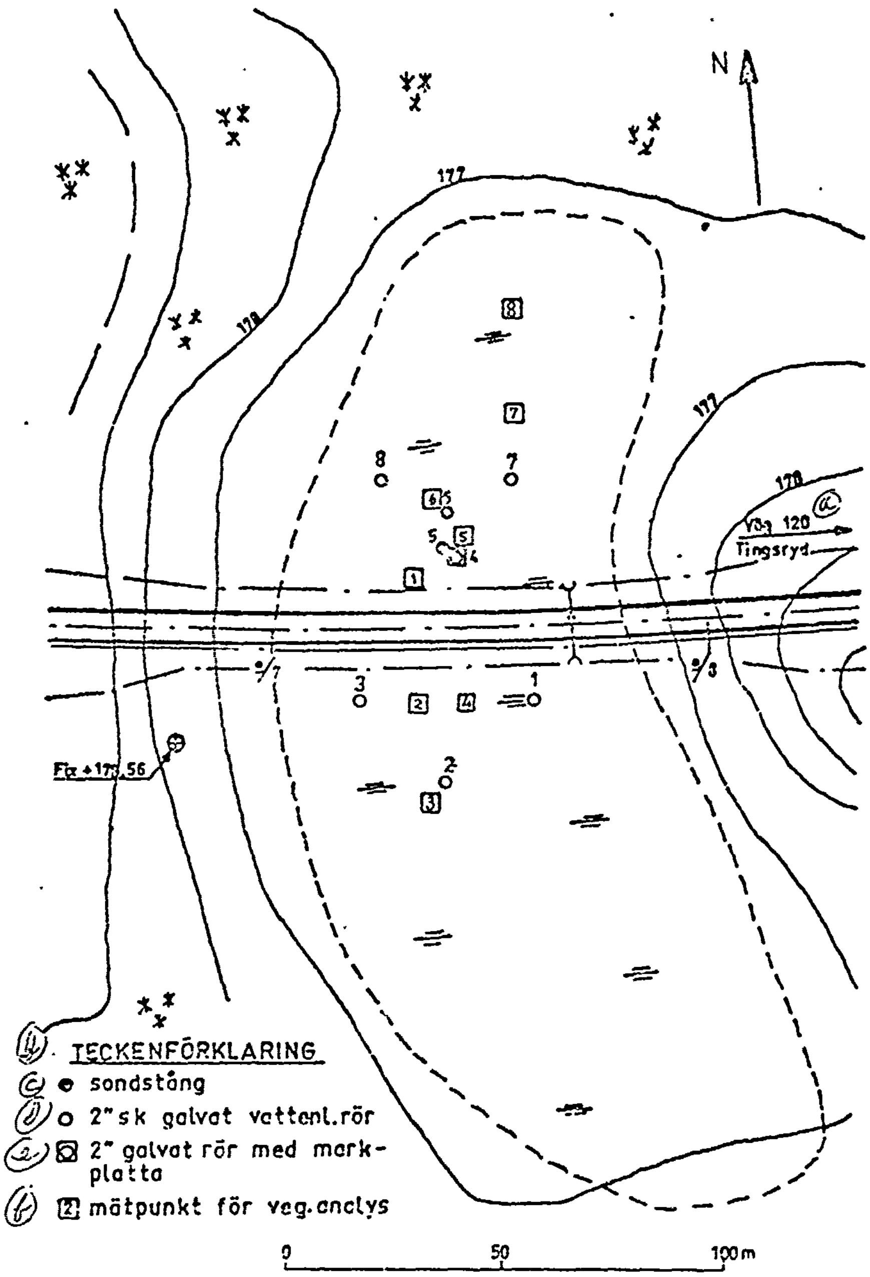
3.2.2.1. Description of the region

The test sites, called Potteboda and Svenslund, are located ca. 4 km east of Häradsbäck along the newly constructed highway 120. The reconstruction primarily involved the reinforcement and widening of the old roadbed. On the Häradsmåla-Potteboda stretch, where the test sites are located, however, a new stretch of road was laid north of the old road. According to the 1975 traffic calculations, the mean annual 24-hour traffic amounted to ca. 500 vehicles.

This stretch of road passes through an extensive marsh and forest region. The terrain is low and broken with low moraine ridges and intermediate marshy areas and small lakes.

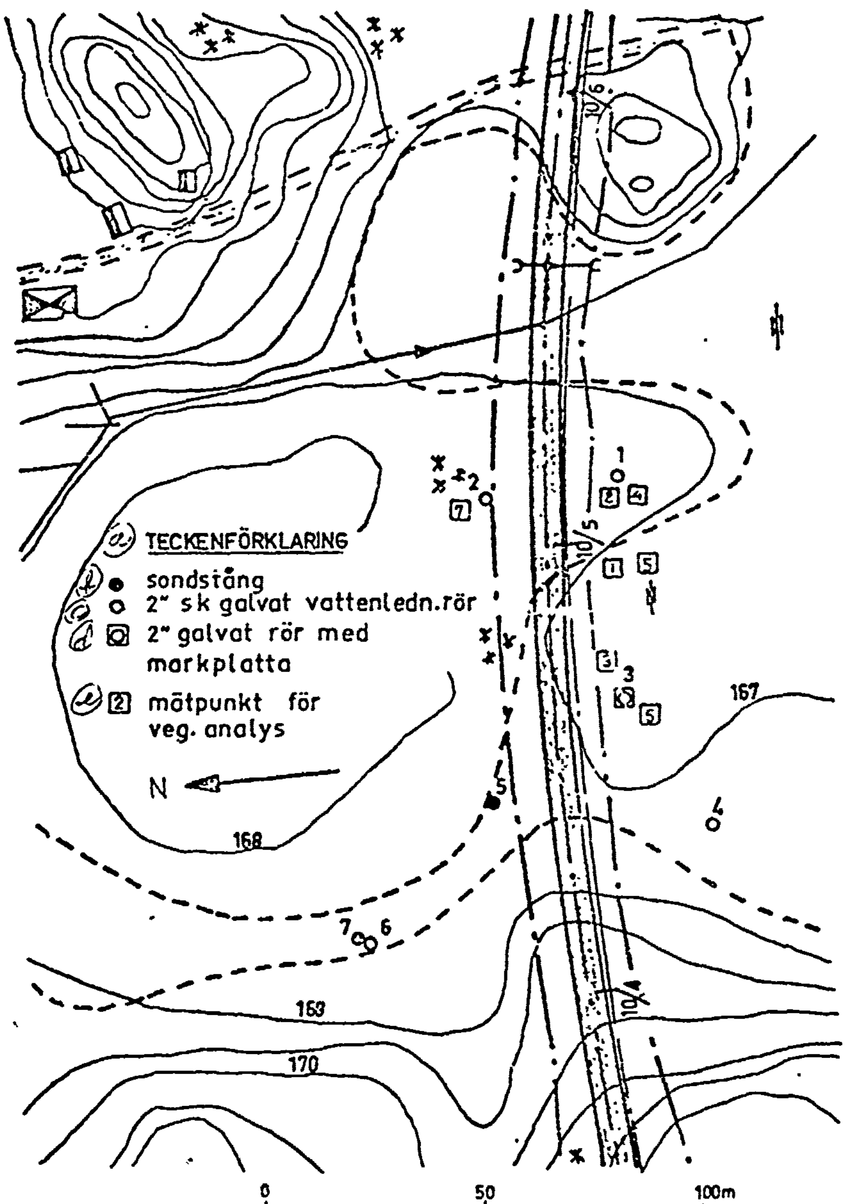
The Potteboda test site consists of a small, well-delineated pine peat bog (Fig. 27). Low moraine ridges are located along the road line on both sides of the peat bog. These ridges consist of a sandy, and in some cases gravelly, moraine, with a high boulder content in the surface. The depth to a solid bottom (moraine) in the peat bog is ca. 3.5 m at the most. The depth is generally considerably less (1-1.5 m).

The Svenslund test site comprises a complex forest and swamp area. The swamp is not so well delineated, but a more solid peat ground section with pine trees extends into the swamp from the north (Fig. 28). North of the road line the peat depth is relatively low (ca. 1 m),



Figur 27. Försöksområde Potteboda. Väg 120, Älmhult-Tingsryd. (The study site Potteboda. Road 120, Älmhult-Tingsryd).

Key: (a) road 120 (b) legend (c) sounding rod (d) 2" galvanized water pipe (e) 2" galvanized pipe with soil-level indicator (f) measuring point for vég. analysis



Figur 28. Försöksområde Svenslund. Väg 120, Älmhult-Tingsryd. (The study site Svenslund. Road 120, Älmhult-Tingsryd).

Key: (a) legend (b) sounding rod (c) 2" galvanized water pipe (d) 2" galvanized pipe with soil-level indicator (e) measuring point for vegetation analysis

while it is considerably greater south of the road (max., ca. 5 m). In the west the region is bounded by a moraine ridge and in the east by a smaller local road and a small moraine hill.

Excavation to a solid bottom and refilling with moraine material were carried out in both the peat bog and the marsh. The excavation was done with a dragline. The excavated material was piled up on both sides of the road line. The moraine material was excavated from the adjoining moraine ridges with crawler tractors.

The excavation work was carried out late in the fall of 1976 (November-December). The highway was opened to traffic in June 1977.

3.2.2.2. Measurements performed

Pipe was placed in the fall of 1974 for measuring the ground water level and sampling in both zones. Eight pipes were placed in Potteboda and 7 in Svenslund (Figs. 27 and 28). A soil-level indicator was installed in both regions for recording possible changes in the level in the ground surface.

The ground water level measurements continued from the fall of 1974 to the fall of 1977 (once or twice a month). The ground water was sampled on two occasions. The samples were analyzed for sodium and chloride content.

3.2.2.3. Results

The results from the ground water level measurements are given in Figs. 29 and 30.

A damming south of the road line (pipes Nos. 1-3) resulted in connection with the excavation work at Potteboda. The water level had risen here ca. 2 dm as compared with the other side.

Rises in the water level were also recorded in some pipes in Svenslund. However, these are not, as in Potteboda, localized to some special site in the zone.

The precipitation data obtained from the SMHI stations of Växjö and Karlshamn are given as the mean monthly values.

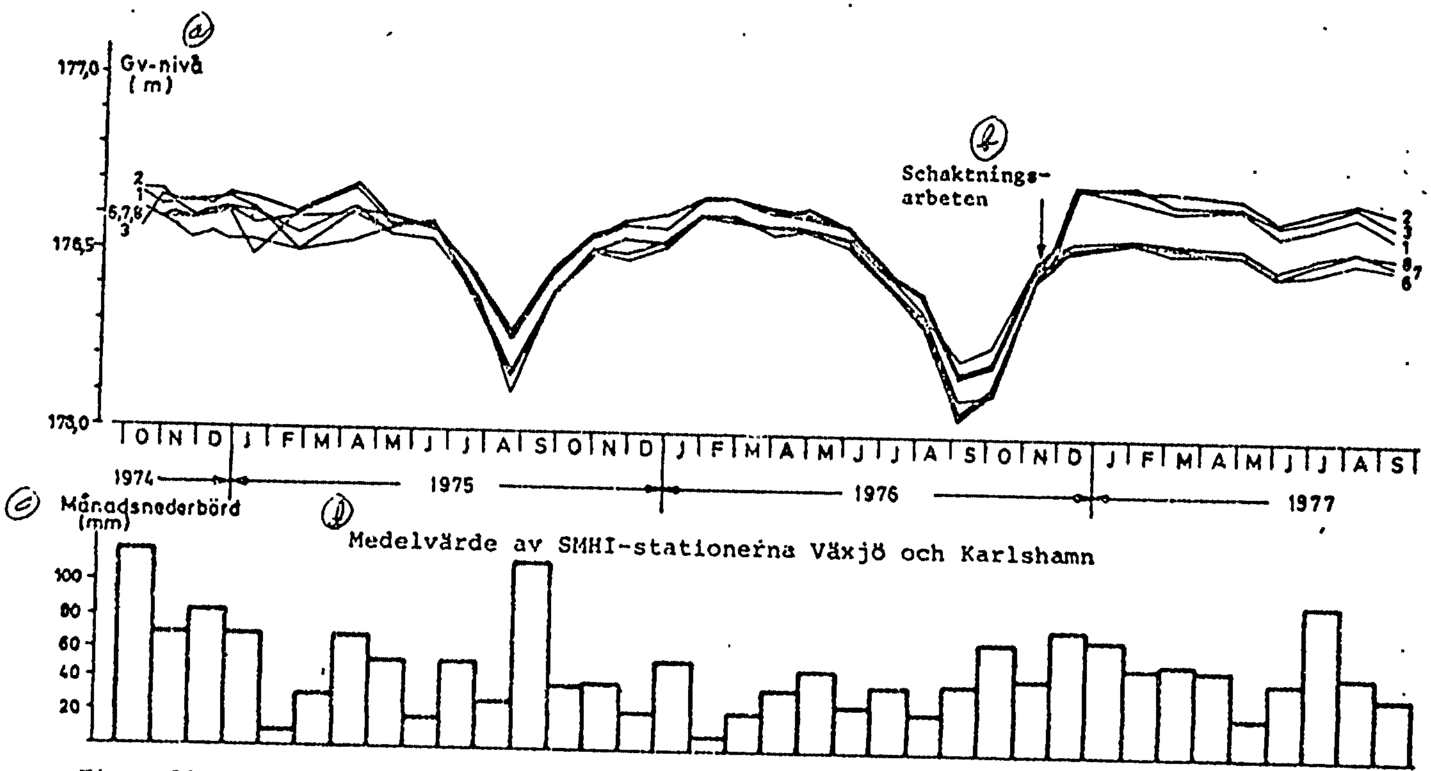
No altitude changes were recorded in the soil-level indicators.

The results of the ground water samplings are given in Tables 8 and 9.

3.2.2.4. Conclusions

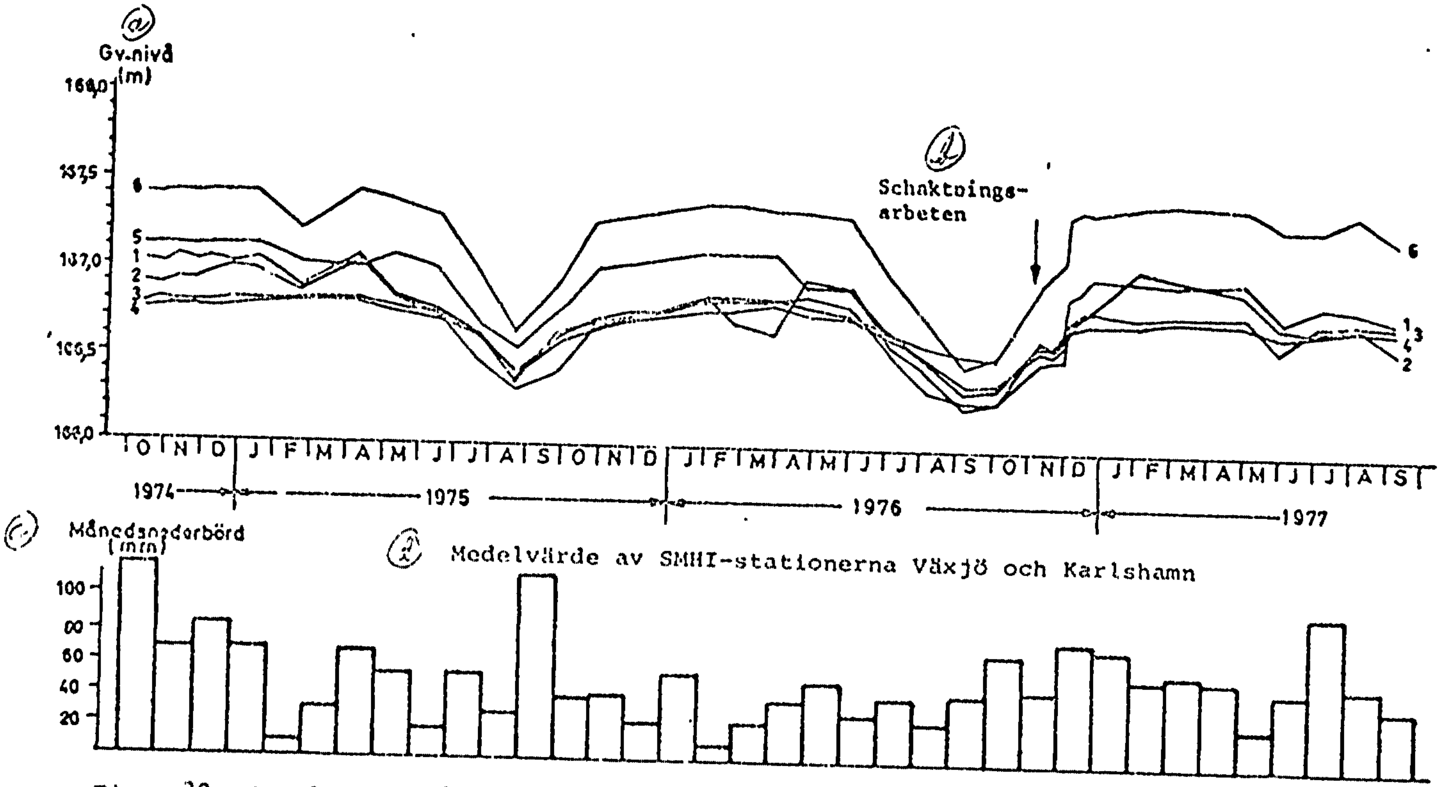
The peat bog in Potteboda was divided into two parts with different water levels due to the fact that the impervious fill material acts as a dam. The southern part of the peat bog is thus in the process of stagnating and with time will turn into a marsh.

The water level rise in Svenslund, noted in some pipes, does not



Figur 29. Grundvattenstånd och nederbörd vid försöksområdet Potteboda.
(Groundwater level and precipitation at the study site Potteboda.)

Key: (a) ground water level (b) excavation work (c) monthly precipitation
(d) mean values of the SMHI stations Växjö and Karlshamn



Figur 30. Grundvattenstånd och nederbörd vid försöksområdet Svenslund. (Groundwater level and precipitation at the study site Svenslund.)

Key: (a) ground water level (b) excavation work (c) monthly precipitation (d) mean values of the SMHI stations Växjö and Karlshamn

Tabell 8. Kalcium-, natrium- och kloridinnehåll i grundvattenprov från försöksområdet Potteboda. (Contents of calcium, sodium and chloride in groundwater samples from the study site Potteboda.)

Rör nr	Kalcium (mg/l)	Natrium (mg/l)		Klorid (mg/l)	
	nov-75	nov-75	juli-77	nov-75	juli-77
1	2,6	7,5	5,5	10,4	10,1
2	4,4	6,5	6,1	11,9	14,4
3	4,6	7,2	4,9	10,4	23,3
4	4,9	7,6		18,9	
6	3,6	6,0	5,6	13,8	14,5
7	2,0	4,8	6,4	7,8	13,3
8	3,1	6,0	5,8	10,8	13,5

Tabell 9. Kalcium-, natrium- och kloridinnehåll i grundvattenprov från försöksområdet Svenslund. (Contents of calcium, sodium and chloride in groundwater samples from the study site Svenslund.)

Rör nr	Kalcium (mg/l)	Natrium (mg/l)		Klorid (mg/l)	
	nov-75	nov-75	juli-77	nov-75	juli-77
1	1,9	2,7	2,6	2,6	3,6
2	2,7	2,4	4,0	7,8	15,0
3	14,0	5,0	22,5	20,0	12,4
4	14,6	6,2	8,6	10,5	16,3
6	10,5	7,1	12,5	11,8	13,4

Key: (a) pipe No. (b) calcium (c) sodium (d) chloride
(e) Nov. (f) July

have the same manifest effect on the environment as in Potteboda. This is due to the fact that the area had already become more or less stagnant.

Upon excavation, the masses were spread relatively far from the road; thus, they cover large areas. This is due to the fact that a dragline was used in the excavation and it has a substantially greater radius of action than excavators (cf. Lindbäck, p. 66). The changes in the natural environment are thus much greater with the construction of this road than of the road E4 at Lindbäck, due to the work method.

The low chloride contents in the ground water, which were measured before the highway was opened to traffic, make the sites suitable for monitoring the effect of road salt on the environment.

3.2.3. Spelnäs, road 893, Sunne-Torsby

3.2.3.1. Description of the region

The road 893 between Sunne and Torsby was rebuilt during recent years. In the Sunne-Stöpafors stretch, where the study site is located, the new road essentially follows the old road right-of-way west of the lake Övre Fryken. According to traffic calculations for 1975, the mean annual 24-hour traffic count is ca. 900 vehicles/24 hours.

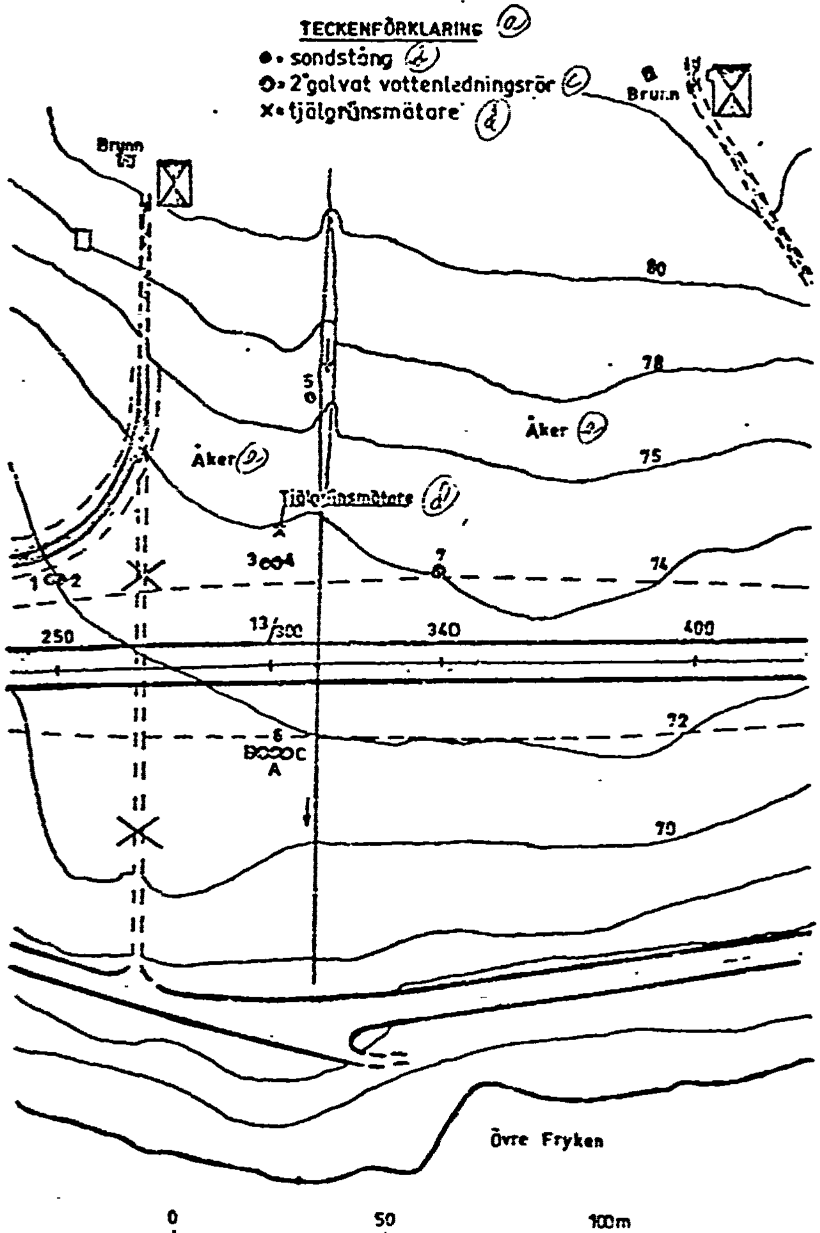
The study site lies on a gentle slope down toward Övre Fryken (Fig. 31). During the reconstruction, a relatively deep cut was made (Fig. 32) in a ridge running crosswise to the road line. The ridge is most likely caused by a mountain back. A portion of this mountain back is exposed in the promontory that projects out in Övre Fryken in the middle of the study site.

The area selected is located on cultivated land; thus, it actually falls outside of the purpose of the project (undisturbed nature). Due to the difficulty in finding suitable study sites and to the fact that the ground layer sequence and the lay of the land was considered of interest from a hydrogeological standpoint, it was decided in any case to conduct ground water studies in this zone.

The soil types at the study site consist of silty and clayey sediment on rock or moraine. The layer sequence, which varies greatly within the actual area, is indicated roughly by the cross sections (Fig. 32).

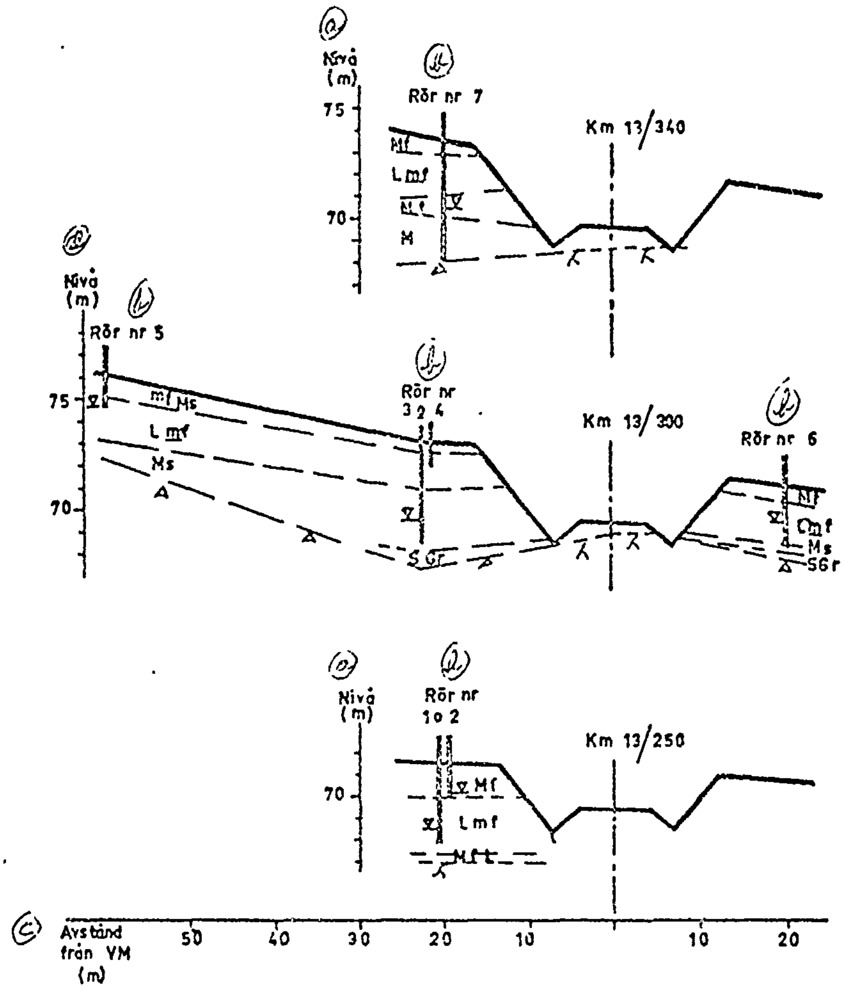
The ground water levels were developed partly in the area of contact between fine clay and overlying fine sand, and partly in coarse sand under clay. The ground water movement is directed out toward Övre Fryken.

Excavation work at the study site was begun during the second half of March in 1975. The digging, which was done with excavators and dump trucks, began from the south (km 13/250). Here the fine-grained material (fine clay with a layer of fine sand) under the terrace level had a very high water content; therefore, the material was dug out to a solid bottom (rock). The excavated material was re-



Figur 31. Försöksområde Spelnäs. Väg 893, Sunne - Torsby.
(The study site Spelnäs. Road 893, Sunne-Torsby).

Key: (a) legend (b) sounding rod (c) 2" galvanized water pipe (d) frost-line measuring gauge (e) field



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grass	Gr = gres	L = lera	clay
sand	S = sand	∆ = morän	moraine
silt	M = mo	⋏ = berg	rock or ledge
coarse silt	Ms = grovmo	▽ = gv-yta vid schaktningens början (1975 - 03 - 15)	groundwater level at start of excavation
fine silt	Mf = finmo		

Figur 32. Tvärprofiler genom försöksområdet Spelnäs.
(Cross-sections at the study site Spelnäs.)

Key: (a) level (b) pipe No. (c) distance from road center line

placed gradually with gravel material.

In an attempt to drain the cut, a ditch was dug along the left slope through the entire excavation. It was finished at the end of March. The rest of the cut was excavated in April.

This stretch of road was opened to traffic in the beginning of September 1975.

3.2.3.2. Measurements performed

Pipes were placed in the fall of 1974 for measuring the ground water level at 5 points within the area (Figs. 31 and 32). Two pipes with perforations at different depths were installed at a couple of points. A pipe for sampling was placed at one of the points, on the lower side of the road (pipe No. 6). The ground water levels were measured in all the pipes from the fall of 1974 to the fall of 1975 (once or twice a month). Ground water sampling was carried out on 3 occasions.

3.2.3.3. Results

The results of the level measurements are given in Fig. 33. The ground water level fluctuated a great deal in all the pipes. At certain periods the water level was below the perforation levels in the pipes.

With excavation the ground water level sank in pipes Nos. 1, 3, and 7 more or less instantaneously by ca. 0.5 m. It is noteworthy that these 3 pipes have a perforation well-below ground level, while the other pipes have the perforation closer to the ground surface. The precipitation data was obtained from the SMHI stations Knon and Arvika and given as mean monthly values.

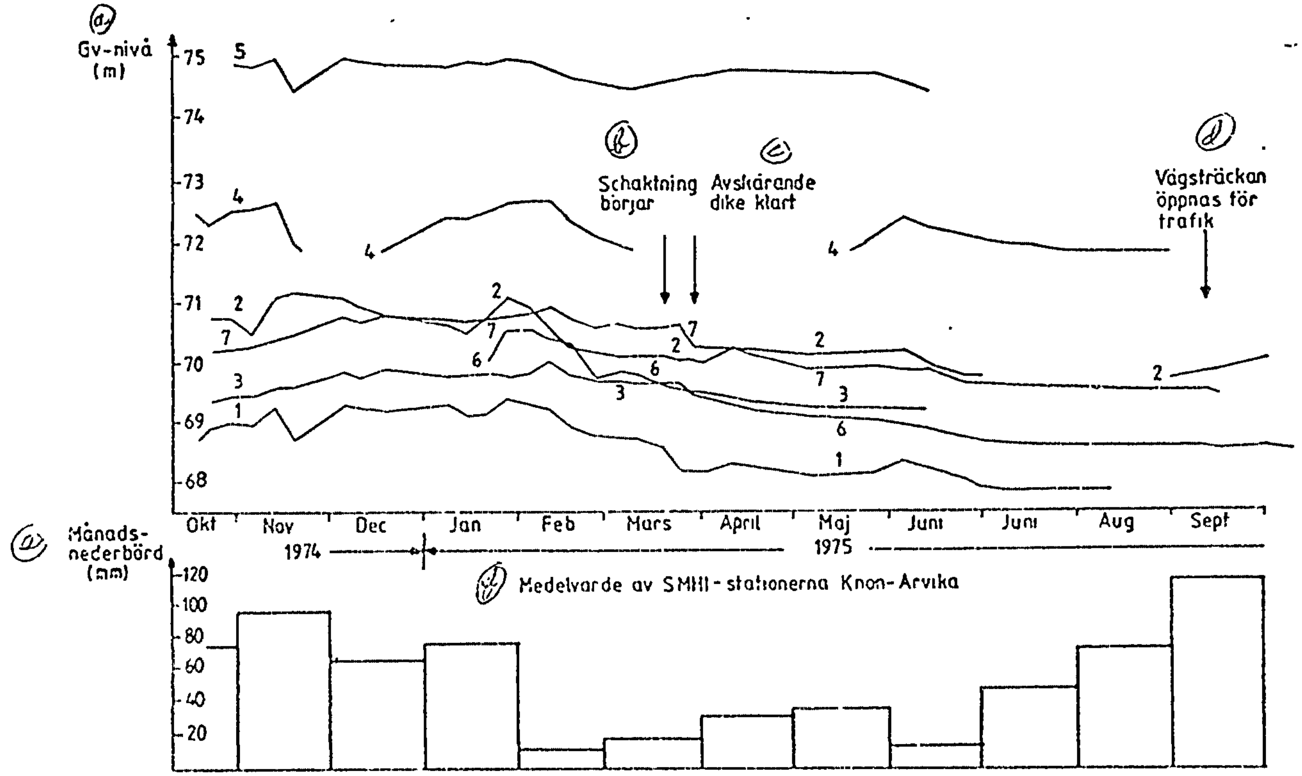
The results of the ground water samplings are given in Table 10. The relatively high sodium values can possibly be explained by the fact that the study site lies on cultivated land.

Table 10. Sodium and chloride contents in groundwater samples from the Spelnäs study site.

Time of sampling	Sodium (mg/l)	Chloride (mg/l)
January 1974	90.0	1.1
October 1975	24.8	1.1
May 1977	48.5	6.6

3.2.3.4. Conclusions

In connection with the excavations, the lower ground water level dropped by ca. 0.5 m, while no drop in the upper level could be noted. The reason for this is probably that the excavation did not disturb the more or less local ground water reservoir that is formed above the clay. See the opposite situation in the excavation at Lindbäck (see p. 29). The vegetation present in the area could possibly be



Figur 33. Grundvattenstånd och nederbörd vid Spelnäs. (Groundwater level and precipitation at the study site Spelnäs.)

Key: (a) ground water level (b) excavation begins (c) cut-across ditch finished
(d) road stretch opened to traffic (e) monthly precipitation
(f) mean values of the SMHI stations Knon-Arvika

dependent on this upper ground water reservoir, but not the lower one. The vegetation should not thus be affected by the excavation. On the other hand, the drop that occurred in the lower reservoir could have caused a possible utilization of the ground water near the road.

The chloride contents measured in the ground water have been very low to date. At the latest sampling, ca. 1.5 years after the road was opened to traffic, a slight increase (uncertain) was however noted in the chloride content.

3.2.4. Liden, Rd 86, Sundsvall-Bispgården

3.2.4.1. Description of the region

The study site is located in the Indal river watershed immediately north of Liden. The site, which slopes sharply to the side, begins at the newly constructed road 86, below the old road 86 (Figs. 34 and 35).

The portion of the site that lies on the upper side of the road consists of cultivated land partially overgrown with brush. Below the road there is a more undisturbed zone of birch forest.

The mean annual 24-hour traffic count was calculated in 1975 to be 660 vehicles/24 hours.

During the reconstruction of road 86 a moderate cut in silty sediment was made. The greater portion of the excavation is taken up by the right-hand ditch (upstream side).

Due to the mild winter, the excavations at the site could be begun as early as February 1975. At that time only a thin surface layer was frozen. The snow depth was ca. 3 dm.

The soil types at the study site consisted of silty sediment on moraine. The layer sequence is roughly indicated by the cross sections (Fig. 35). Approximately 2-3 m of silt overlies a thinner layer of fine sand (0.5-1 m) nearest the moraine.

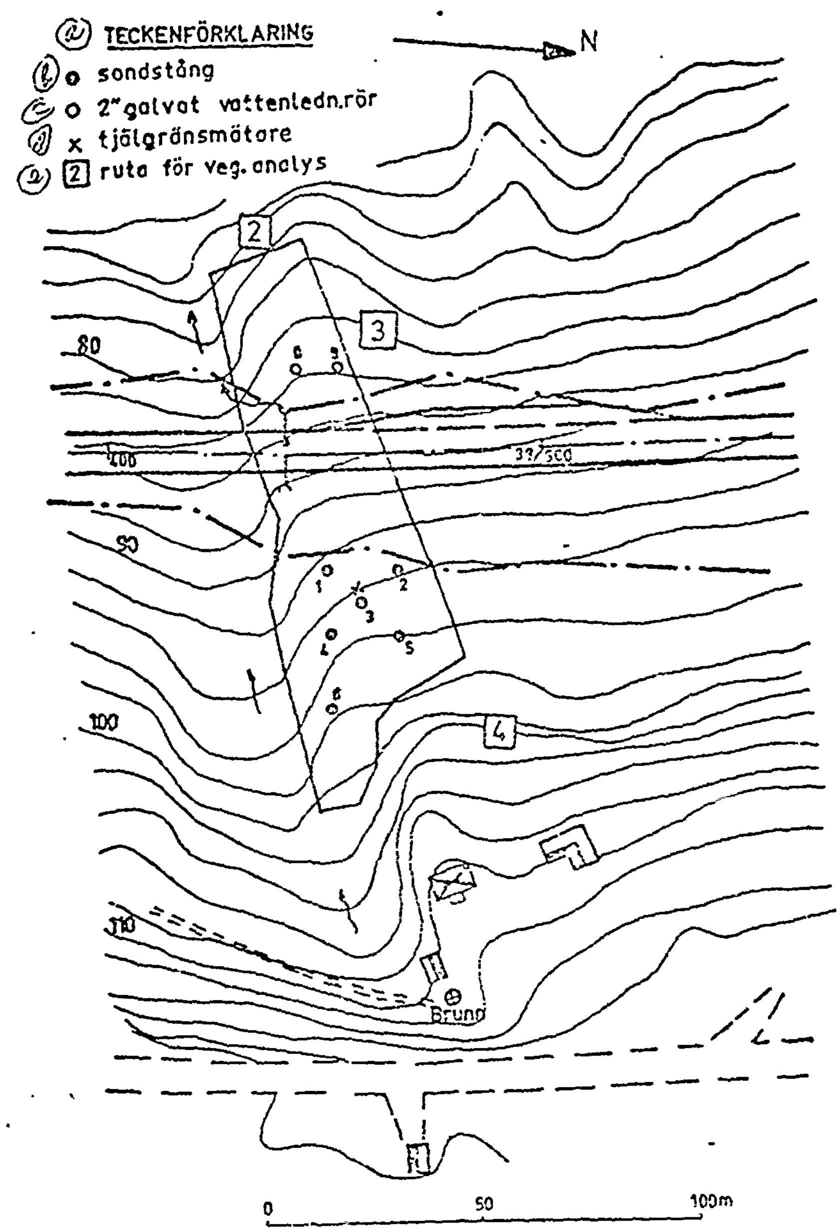
The ground water level lies alternately in the fine sand layer and in the uppermost part of the moraine. At a couple of sites on the downstream side the ground water emerges aboveground in the form of springs.

In view of the climatic conditions and the steep, high valley sides, it is probable that large amounts of surface water are drained by the highway ditches on certain occasions.

3.2.4.2. Measurements performed

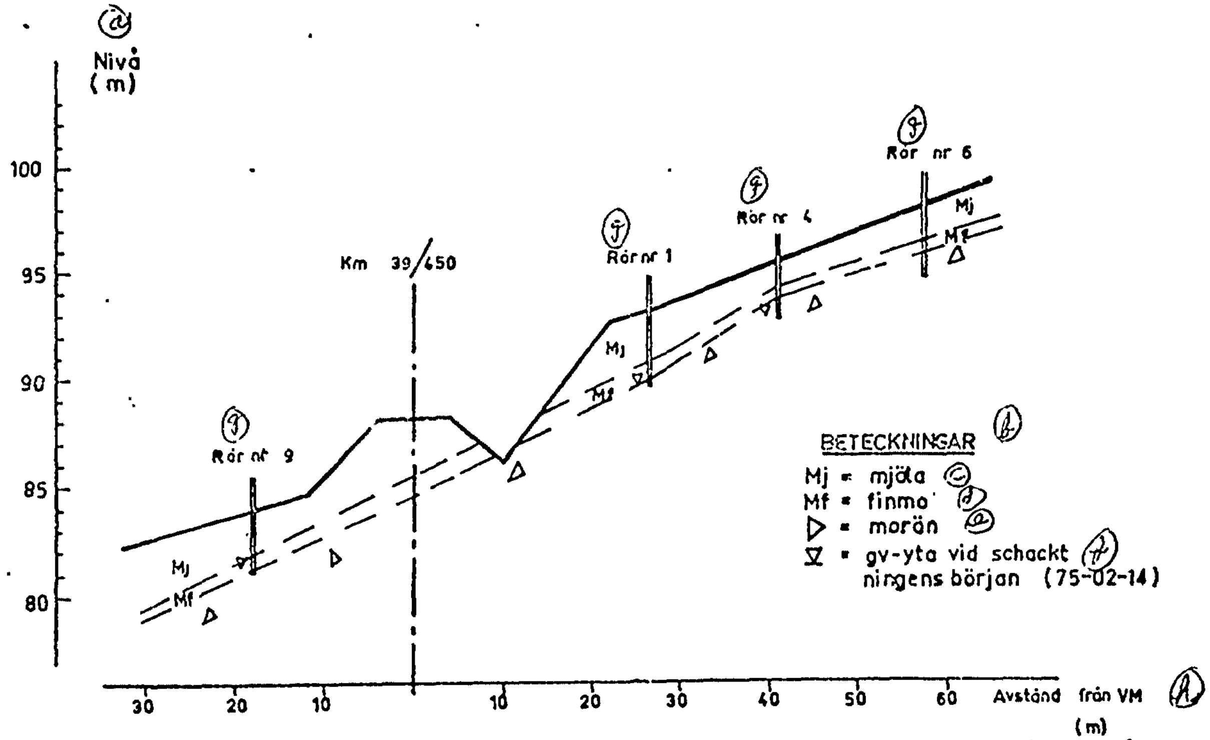
During the fall of 1974 pipes were placed for ground water level measurements at 8 points within the site (Fig. 34). Ground water sampling was possible in two of these pipes, on the lower side of the road.

The ground water levels were measured in all the pipes from the



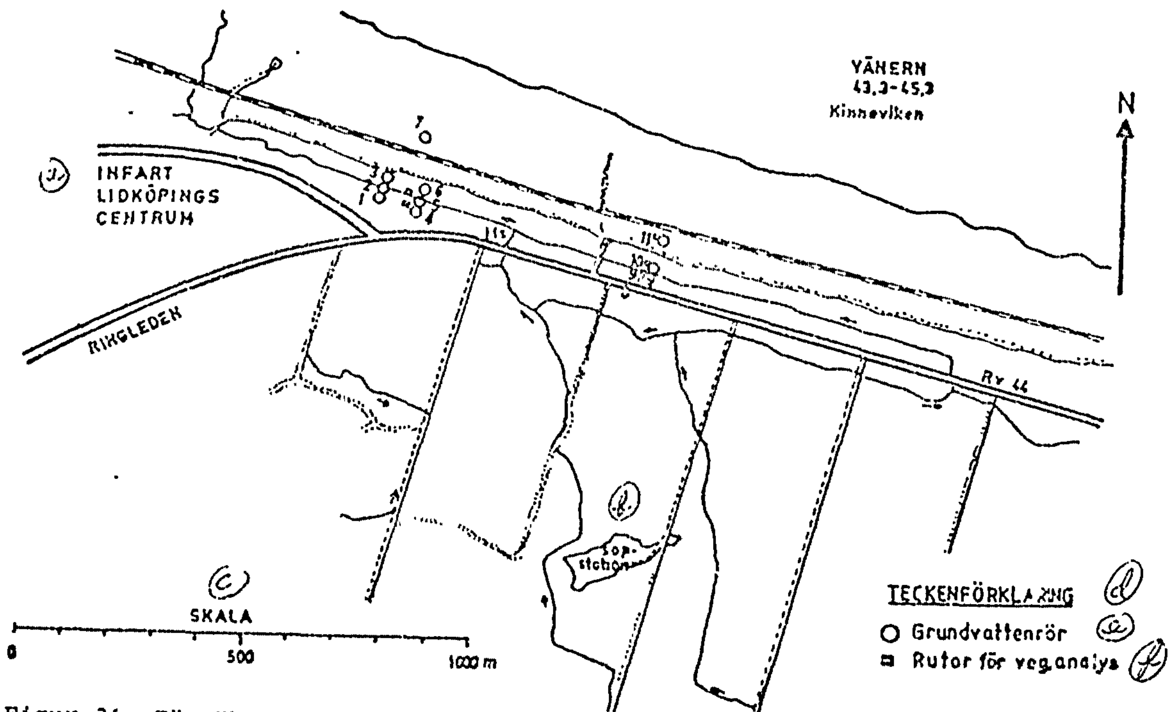
Figur 34. Försöksområde Liden. Rv 86, Sundsvall-Bispgården. (The study site Liden. Road 86, Sundsvall - Bispgården).

Key: (a) legend (b) sounding rod (c) 2" galvanized water pipe (d) frost-line measuring gauge (e) areas for vegetation analysis



Figur 35. Tvärprofil genom försöksområdet Liden. (Cross-section at the study site Liden.)

Key: (a) level (b) symbols (c) silt (d) fine silt (e) moraine (f) groundwater level at the start of excavation (g) pipe No.



Figur 36. Försöksområde Lidköping. Rv 44, Lidköping-Mariestad. (The study site Lidköping. Road 44, Lidköping-Mariestad.)

Key: (a) entrance to downtown Lidköping (b) central garbage collection station (c) scale (d) legend (e) groundwater pipes (f) areas for vegetation analysis

fall of 1974 to the summer of 1975 (once or twice a month). Ground water sampling was carried out on 3 occasions.

3.2.4.3. Results

The results of the level measurements show that the fluctuations in the ground water level were very small. The ground water level was also low near the moraine surface. No effect whatever on the ground water level could be observed, either during the excavation or during melting of the snow.

3.2.4.4. Conclusions

The ground water level at the site is not affected by the excavation work. A possible explanation for this could be that the gradient along the steep valley sides is so great that no detectable fluctuations in the ground water level occur with such a moderate excavation as involved here.

3.2.5. Lidköping, Road 44, Lidköping-Mariestad

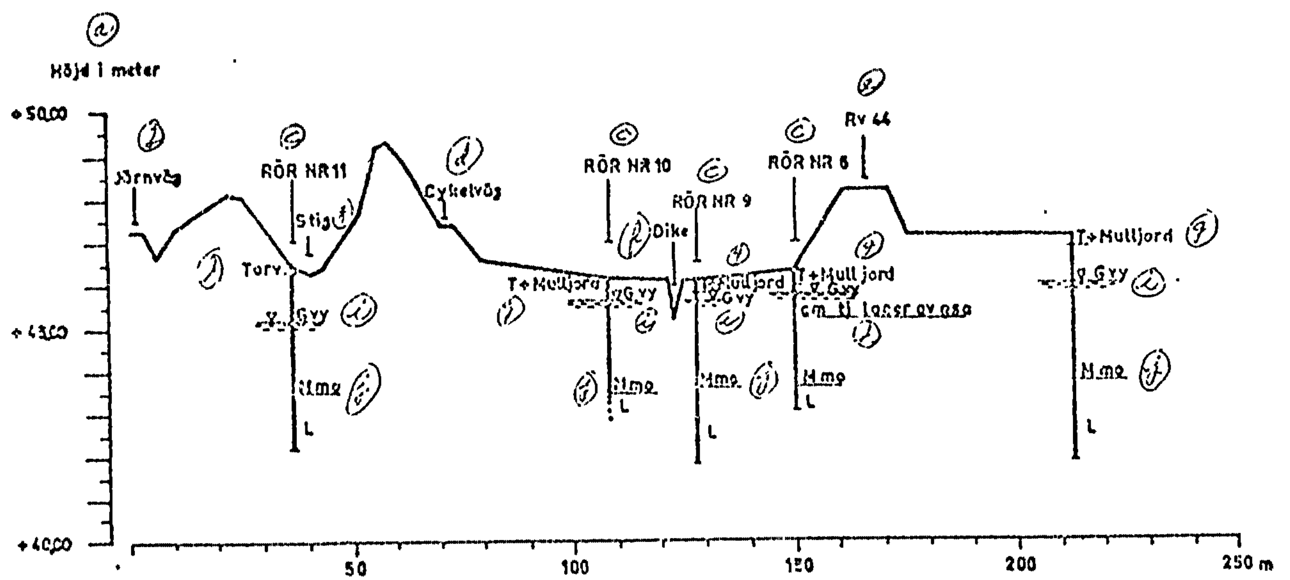
3.2.5.1. Description of the region

At the end of the 1960's relatively extensive damage was observed in a forest stand (primarily spruce) along Road 44, ca. 3 km east of Lidköping. The damaged zone extended from the approach to downtown Lidköping ca. 2 km easterly along the road (Fig. 36). The damage was restricted to the north side of the road and to a distance of 60-70 m from the road. During subsequent years the damage became more and more extensive and the owner of the land (the community of Lidköping) was compelled to log off a relatively large portion of it. In July 1974, contact was therefore made with the forestry service in Skaraborg province in an attempt to determine the causes of the damage.

During the investigation thereby conducted, it was found that the stand had not been attacked by insects, which was worthy of note because a number of spruces had assumed a reddish color. In collaboration with the municipality of Lidköping, samples were taken of the ground water and conifer mass on two occasions (December 1974 and May 1975). The results showed that the chloride contents, both in the ground water and the needle mass of the trees, were considerably above normal. The contents in the ground water were 5-10 times higher than the normal values and a good 10 times higher than the normal values in the needle mass [16].

At an early stage it was suspected that the chloride contamination could have originated from the nearby garbage dump (Kartås dump), located ca. 500 m south of Road 44. Tests on the surface water from the dump (the ditch) revealed however that the chloride contents in the runoff water were completely normal. Furthermore, there was no damage to the forest stand lying between the dump and the damaged area by the road. The Kartås dump was thus excluded as a pollution source.

Suspicion was instead directed toward the highway and road salt.



Figur 37. Tvärprofil genom försöksområdet Lidköping. (Cross-section at the study site Lidköping.)

Key: (a) height in meters (b) railroad (c) pipe No. (d) bicycle path (e) road 44
(f) ditch (g) peat plus humus soil (h) peat (i) ground water level
(j) medium sand

The damage was limited to a zone near the road and according to certain information there must have been abnormally heavy salting. This information was, however, confirmed by the owner of the road (the community of Lidköping).

During the summer of 1975, the area was inspected by representatives for this project ("VIPON"). The site was considered to be so interesting that it was decided that the studies initiated should continue within the frame of the "VIPON" project.

The zone is located on a shore stratification inside of Kinne bay. This stratification, called Kartåsen, is described quite thoroughly in the description for the Lipköping geological mapsheet [17]. The stratification, which consists primarily of sand, is deposited on glacial clay. The thickness of the sand in the actual site is ca. 3 m. Beach dunes have built up at some sites. The damaged area is bounded in the north by such a beach dune (Figs. 36 and 37).

The ground water level lies relatively close to the ground surface. On some occasions, portions of the site are flooded. The entire site is flat; therefore, the horizontal ground water flow presumably is slow.

No major road construction work has been carried out in the study site in recent years. Some improvement work was done in 1960, when the road was raised ca. 30 cm. The road now lies on a 2-meter embankment. The road stretch itself is old. Only a minor alteration of the road was made in connection with the laying of a pipeline. This alteration involves only the most westerly portion of the site (Fig. 36).

The mean annual 24-hour traffic on the actual stretch of road is 5750 vehicles according to 1975 calculations.

3.2.5.2. Measurements performed

Eleven pipes for ground water sampling were placed within the zone. It is evident from the plan map (Fig. 36) that the pipes were placed in 3 profiles perpendicular to the road line. The community of Lidköping set out pipes Nos. 1-7 and took samples on 2 occasions, the fall of 1974 and the spring of 1975. In connection with the laying of the pipeline, these pipes ended up a bit further from the new road. Consequently, through the instrumentality of VTI four additional pipes (Nos. 8-11) were installed further east in the zone in the fall of 1975. Samples were taken in all the pipes on 3 additional occasions. All the pipes in the area are of plastic (50 or 100 mm in diameter) and were either dug down or pressed down into previously drilled holes. The perforations in the pipes were at the level of the sand layer, and therefore, they had no contact with the underlying clay.

The surface water samplings were repeated in the spring of 1977. Samples were taken in the ditch, some in the vicinity of the dump and some in the damaged area.

Borings were made down into the clay in order to establish the

thickness of the sand stratification. Disturbed samples of both sand and clay were taken thereby. Some of these samples were analyzed with regard to sodium and chloride content.

3.2.5.3. Results

It is evident from the level measurements that the ground water level lies near the ground surface (0.5-1.0 m) and that the fluctuations are relatively insignificant. The gradient of the ground water surface shows that the ground water flows in a northwest direction out toward Kinne bay (Kinneviken). The gradient is very moderate; consequently, the horizontal flow rates are low.

The results of the ground water samplings are given in Table 11. The sodium and chloride contents measured are, as can be seen, very high. It should be noted that the maximum contents are not found nearest the road, but ca. 30-40 m from the road edge. Nor do the contents exhibit a seasonal variation.

Sòme of the ground water samples taken by the K-ministry at the Kartås dump show equally high chloride contents (200-300 mg/liter).

On the other hand, the samples taken of the surface water in the vicinity of the dump have completely normal chloride contents (20-60 mg/liter).

Analyses of the soil samples taken in the borings show that the clay has high chloride contents, which increase with the depth. The contents in the sand stratification are considerably lower, but in the lower portion nearest the clay, the contents are increased (Fig. 38).

3.2.5.4. Discussion and conclusions

It is perfectly clear that the damage in the forest stand was caused by high chloride contents in the ground water. This hypothesis is reinforced by the needle samples taken on the damaged trees. However, the cause of the increased chloride content in the ground water is more difficult to determine.

The theory that the chloride in the ground water should come from road salt is plausible in view of the fact that the damaged area lies in the immediate vicinity of the road. However, several factors speak against the theory. Thus, the highest chloride contents were not measured closest to the road, but some distance away from it. Nor do the contents exhibit any seasonal variation, which would be natural if they were caused by road salt. In view of the maximum quantities of salt that could have been spread on the road, the chloride contents also appear to be unreasonably high. Finally, high chloride contents in the ground water were also measured at the dump, about 500 meters south of the road. These contents cannot reasonably have any connection with highway salting.

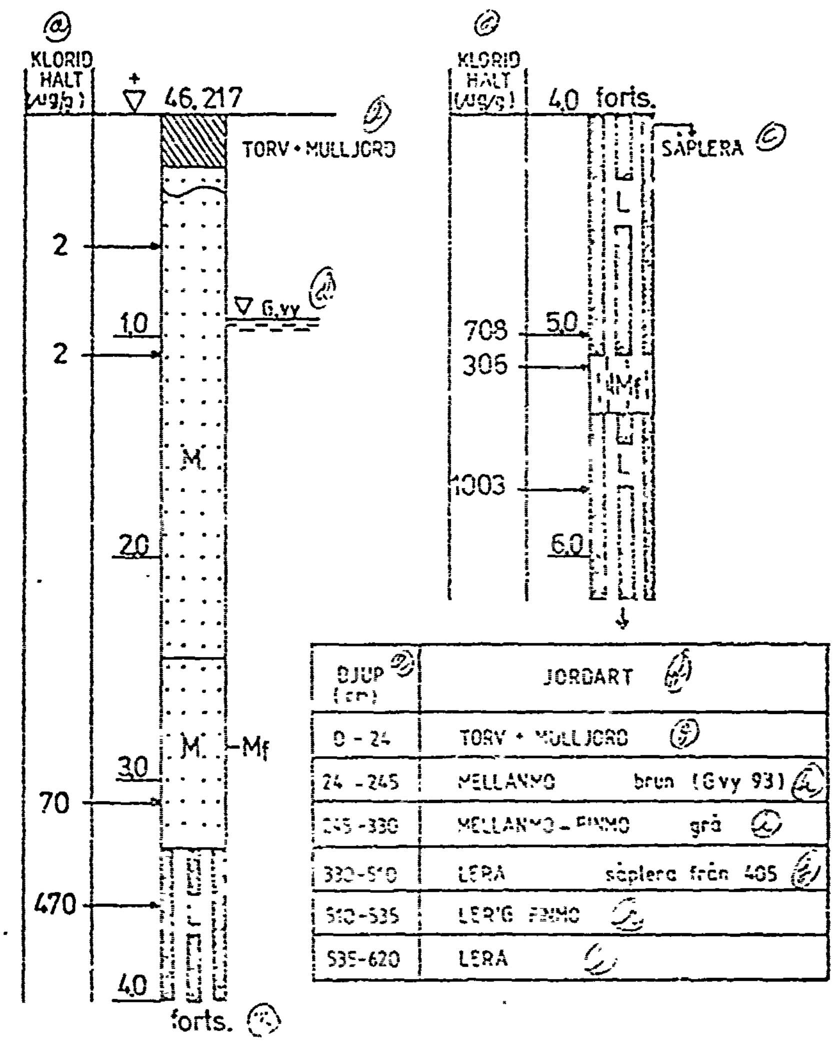
It does not appear to be plausible either that the chloride should originate from the dump. To be sure, high chloride contents were meas-

Taboll 11. Natrium- och kloridinnehåll i grundvattenprov från försöksområdet Lidköping. (Contents of sodium and chloride in groundwater samples from the study site Lidköping.)

(a) Rör nr	(b) Avstånd från vägkant (m)	(c) Klorid (mg/l)					(d) Natrium (mg/l)		
		dec-74	maj-75	nov-75	maj-76	april-77	nov-75	maj-76	april-77
1	15	124	70	86	101	49	27	27	19
2	35	220	224	334	313	255	81	100	89
3	65	35	11	30	19	14	16	13	13
4	15	248	140	229	213	150	90	135	92
5	35	236	220	255	270	210	153	109	92
6	65	348	244	157	266	360	117	176	207
7	175	47	39	65	49	61	23	32	34
8	11			83	105	136	41	58	81
9	33			232	245	238	108	125	128
10	53			432	390	149	153	190	94
11	136			65	28	16	29	16	8

Key: (a) pipe No. (b) distance from road edge (m) (c) chloride (d) sodium

Key: (a) chloride content (b) peat plus humus soil
(c) soap clay (d) ground water level (e) depth
(f) soil type...



DJUP (cm) (e)	JORDART (f)
0 - 24	TORV + MULLJORD (g)
24 - 245	MELLANMO brun (Gvy 93) (h)
245 - 330	MELLANMO - FINMO grå (i)
330 - 510	LERA såplera från 405 (j)
510 - 535	LER'G FINMO (k)
535 - 620	LERA (l)

Figur 38. Borrprofil från försöksområdet Lidköping belägen mellan grundvattenrör 1 och 4. I kolumnen till vänster anges kloridhalterna i de upptagna jordproven. (Boring at the study site Lidköping located between observationwell No 1 and 4. The chloride content of the soil samples are indicated in the left column.)

(g) peat plus humus soil (h) medium sand brown
(GWL 93) (i) medium sand-fine sand gray
(j) clay soap clay from 405 (k) clayey fine sand
(l) clay (m) continuation

ured in the ground water at the dump, but the samples taken of the surface water from the dump exhibit completely normal chloride values (20-60 mg/liter). Nor is it known that any refuse containing chloride had been deposited at the dump, and there is no vegetation damage in the forested area between the dump and the road.

Thus, it is not likely that the elevated chloride contents could have been caused by either road salt or any chloride-containing refuse at the dump.

One possible explanation is that the chloride originates from the glacial clay under the sand stratification. This clay was, after all, deposited in salt water and the sampling also shows that the salt contents are substantial (Fig. 38). The salt is present in the pore water of the clay and for it to be released, it is necessary that the clay be worked in some manner. It is possible that the weight of the Kartås dump became so great with time that the clay was compressed and the pore water containing salt was thus pressed out.

The fact that damage to the forest was not encountered elsewhere than by the road could be explained in that the water containing the salt requires a certain distance for it to spread to the upper ground water layer. The damaged area also lies in a weakly marked low point (Fig. 37). These factors could work together so that the ground water containing the salt lies closest to the ground surface at the actual site involved. In order to support this theory, it would be necessary for the studies and samplings to be extended to a larger area. Some form of tracer-material studies could also be required.

Highway salting thus did not cause the extremely high chloride contents in the ground water. Road salt was undoubtedly a contributing factor, but certainly did not affect the levels to any decisive degree. Most of the chloride present in the ground water probably originated from the underlying clay.

Due to the special conditions (relatively thin layer of pervious sand on tight clay), the area is quite generally very sensitive to pollutants. It can be considered a typical example of a pollution-sensitive zone.

3.3. Effects on the ground water

The following section is an attempt to summarize the information obtained in the project and the experience concerning the effect of roads on the ground water conditions. Some of the information presented here has been taken from the literature, and some from studies conducted at the test sites, as reported in the project.

However, it is only the short-term effects caused by road construction that have emerged to date in the study sites. The long-term effects, caused by traffic and road maintenance, have not yet been manifested. Some of the study sites, as established, are however apparently suited for studying these effects. This is particularly true of the study sites Lindbäck and Potteboda-Svenslund (Sections 3.2.1. and 3.2.2.). The documentation of these sites, which was obtained

prior to road construction, essentially corresponds to undisturbed natural conditions, since in both cases, a new stretch of road was constructed.

3.3.1. Changes in the ground water level

3.3.1.1. Lowering

A lowering of the ground water level can occur through increased drainage in connection with the road and in conjunction with excavations below the ground water level. To a certain extent, the reduced infiltration as a result of paving and other compaction of the road surface can also induce a lowering of the ground water level. However, it should be considered to have relatively little effect due to the fact that the actual highway involves a comparatively narrow strip in the terrain. Of course, the effect becomes much greater if extensive, connected areas are involved [18].

The drainage effected in connection with roads is for the purpose of carrying off the surface water and draining the upper structure of the road. The most intensive drainage effect is obtained if the road is laid in a cut in a slope with a thin layer of water-pervious soil on rock or directly on fissured or weathered rock. As a result, the flow paths for both surface and runoff water as well as superficial ground water below the slope are cut off in a certain stretch. The downstream effect is dried-up wells (example from Södermanland according to T. Lundgren, verbal information) and springs, and drought-damaged vegetation, which was observed, e.g., at the Sollefteå study site (Section 2.2.16.). It is noteworthy that no effect on either ground water level or vegetation could be detected at the Liden study site (Section 3.2.4.). In that area the road diverts the natural water flow very sharply.

Most vegetation types that are dependent only on the water in the soil are affected only locally downstream from the road. The ground water-affected vegetation types, such as swamp forest and, e.g., spring peat soils can, on the other hand, be affected at greater distances downstream.

In the USA a relatively great significance is attributed to the effect on the superficial ground water if this ground water originating from more elevated forest regions has a better quality than the ground water in heavily populated or agricultural areas in the valleys and in some places is also present in such large amounts that the water supply for smaller towns may be based on such ground water availability [19].

Drainage and diminished infiltration cause an unintended drop in the ground water level. A deliberate drop is effected in connection with excavations below the ground water level. The magnitude of the drop is determined vertically by the actual need and horizontally by the local hydrogeological conditions. In tight ground layers it is generally a question of a very restricted cone of depression, while kilometer-wide cones of depression can be formed in soil and rock with good water-permeability in certain layers or when an artes-

ian ground water level drops [12]. This can result in a reduced water availability in wells, settling in clay, and a diminished water supply in artesian wells, on which certain sensitive vegetation types may be dependent. The lowerings are however usually slight and limited to the immediate vicinity of the road. Such a minor lowering was obtained at the Lindbäck study site in connection with the excavation work (Section 3.2.1.).

In the case of high rock cuts as well as in-ground cuts in permeable soil types, there is frequently an intensive drainage in the vicinity of the road. The effect of the drainage is drought-damaged vegetation or changes in the composition of the vegetation. The latter effect was observed, e.g., at the Gundlatorp study site (Section 2.2.8.).

3.3.1.2. Damming

Roads can cause a damming effect if the material in the fills, especially in the case of excavations in peat lands, consists of compact soil types or if the excavated masses are impervious (clay, mud) and are deposited along the road.

With regard to excavations in peat soils, the damming effects more or less generally occur. Damming has also occurred at the Lindbäck and Potteboda/Svenslund study sites (Sections 3.2.1. and 3.2.2.) and in the case of some lesser peat soils in the construction of E4, Nyköping-Lästringe, where, for example, a pine peat bog acquired a raised water level, whereby the pines "were suffocated" and a more hydrophilic vegetation began to take over. The water level rises that occur are usually slight (2-3 dm), but are still sufficient to alter completely the conditions for the vegetation. The eason why these effects are so little considered is probably that wetlands to date have not been considered to have any great economic value. Otherwise, from the purely technical standpoint it would be quite simple to eliminate these effects.

Another effect that arises in the excavation of peat soils is that the excavated masses, especially when working with a dragline, are spread over large areas and thus induce substantial changes in the soil and vegetation. Damming effects have also been observed in flat moraine regions with diffuse surface drainage (almost stagnation). In connection with intensive snow melting or heavy rains, the body of the road forms a dam such that the terrain upstream is inundated.

3.3.2. Pollutants

Pollutants from roads and highway traffic can arise in various instances and can be of different types.

(a) During the construction of the road, partly from the construction activity (oil spills, etc.) and partly due to the fact that special materials (bark, slag, etc.) are used in building the road and give rise to leaching products (humic acids, phenols, sulfur compounds).

(b) During the maintenance of the road, with the use of chemicals for combatting slipperiness on more heavily travelled roads (primarily

NaCl), dust-binding on gravel roads (road salt/$CaCl_2$/ and previously road lye), and formerly for combatting plant growth on the road shoulders.

(c) During travel on the road, partly from vehicles (heavy metals, gaso, oil, and asphalt) and partly due to accidents in transport of dangerous materials, and partly from motorists, especially at rest sites.

The major proportion of known cases of ground water contamination in the vicinity of highways is caused by road maintenance, primarily the use of salt. According to an inquiry sent by SNV (in 1969) to the provincial authorities, the number of unmistakeable cases during a 10-year period is ca. 40 [12]. Of these, approximately two-thirds occurred in the vicinity of salt stockpiles. This latter type of damage appears to have ceased after an improvement in highway department stockpiling practices. The wells that were polluted were generally shallow wells, either lying very close to the road (or the stockpile) or dug in pervious soil types. However, there are examples of wells drilled in rock that have become polluted at a distance of several hundred meters [12]. The experience of salt contamination from roads is similar in other European countries with winter road maintenance [20] and in the USA and Canada. This type of pollution appears to be quite common in the USA, with hundreds of damage cases being reported in some States [21].

Chloride contents above the taste limit are not dangerous to health. On the other hand, sodium levels of ca. 20 mg/liter can be dangerous for persons with heart and kidney diseases. In Massachusetts there were some 90 municipal water supplies with excessively high sodium contents in 1976. It is calculated that as many as 5% of the population that utilizes these water supplies can be harmed by the high sodium levels [22].

It has been found that the high salt levels found in the ground water at the Lidköping study site probably are not caused by road salt (Section 3.2.5.). The region is however a typical example of a pollution-sensitive zone. The area is flat and the soil type is pervious to water. The ground water level lies near the surface of the ground and water exchange in the ground water storage is poor.

Pollutants in the ground water in connection with road construction do not appear to be significant. In one case the driving of piles resulted in the polluted surface water being able to pass through an impervious layer of clay [19]. Special road materials have caused contamination of the ground water: for example, blast furnace slag in the Ruhr region of Germany and bark as frost insulation in the province of Västernorrland [12], as well as siliciferous types of rock, used as fill in roads in the Stockholm district [23].

No definitely confirmed cases of damage to the ground water due to the universal, continuous spreading of pollutants by traffic and motorists have been found in the literature or indicated in inquiries. The heavy metals, primarily lead, can however constitute future sources of pollution. The lead that is dispersed from gasolines in the form of lead halides is converted to lead oxides and

lead carbonates in the air, which are rapidly dissolved in the soil. The free Pb ions are complex-bound (chelated) to organic material or clay colloids [12]. The metal complexes that are formed are very stable and can be presumed to begin migrating in the soil and reaching down to the ground water. The complexes are neutral or negatively charged and are not therefore generally adsorbed in the soil. It can be mentioned in passing that the trace substances that along with chlorides and tritium have proved most suitable for following the ground water flow are specifically metal chelates.

3.3.3. General conclusions

The largest ground water supplies in Sweden are in pebble stone ridges. Approximately 40% of the communal water supplies are based on natural and artificial ground water from pebble stone ridges, and of the number of water supply systems for populated areas in Sweden, more than half are in ridges [24]. For a long time roads have been constructed along the ridges and now they constitute a potential pollution risk for the ground water. Point discharges, accidents which involve leaking tank trucks, or more diffuse pollution sources in the form of road salt may be involved.

Protective zones should be established around municipal water supplies. Whether road construction will be permitted within these zones is now determined differently in different parts of the country. One of the more urgent research projects should therefore be to develop common evaluation bases in these questions, so that guidelines can be formulated and measures taken to protect ground water supplies in connection with existing highways and with the construction of new ones.

4. SURFACE WATER

Due to the restrictions initially imposed on the scope and goal of the project (see Section 1), no specific studies with regard to surface water were conducted within the frame of this project. Some of the effects on surface water by roads are however well-known through the relatively abundant data found in the literature.

Surface water contamination from highways has thus been observed in a number of studies domestically as well as abroad [12]. It is primarily from the streets in heavily populated areas and from roads and trunk lines that significant amounts of pollutants are transported into watercourses and lakes, partly in suspension (rock dust, rubber) and partly in solution (oil, chlorides, phosphorus, nitrogen, heavy metals, and bacteria). Most of the salt used for de-icing highways is deposited during the winter in the snow banks within 3 meters from the edge of the highway. The chloride content in the smaller ditches next to the road thus increases rapidly during occasional thaws and when the snow melts in the spring. The peak chloride levels in such situations are, however, frequently over within less than one week. A few secondary peaks then follow when there are heavy rains during the spring and early summer, after which the chloride content drops slowly to the base level, which is reached in late autumn and early winter. Nevertheless, the dilution is so great during the spring

flood in many watercourses that the chloride content is then minimal. On the other hand, an increase can occur during the time of low water flow in the summer through the outflow of ground water having an elevated chloride content due to road salting. No information has been found in the literature on serious damage to bodies of water caused directly by the chlorides introduced. On the other hand, American studies have shown that elevated chloride contents in small lakes, closed-off bays, etc. due to a change in the salt content can cause the seasonal mixing to be delayed or not occur at all. This can prevent temperature equalization and alter the acidulation, whereby the conditions for living organisms are greatly modified. Another effect of salt pollution from roads observed is that sodium and calcium ions through ion-exchange processes can also liberate mercury and probably other heavy metals from the sediment on lake bottoms.

The danger of contamination is particularly great when roads are constructed on long fills along the edge of or through lakes and shallow ocean bays. In such cases, traffic and road maintenance will constitute a potential pollution risk. Of course, this pollution risk becomes particularly serious if the lake or watercourse involved is a surface water supply. There are examples of heavily-travelled roads that pass alongside of or even through surface water supplies (E4 at Böksjön, Kolmården, road 40 at Delsjöarna, Göteborg, and E4 through Bölesjön, Sundsvall-Härnösand). In view of the fact that the water supply is based almost exclusively on surface water in some parts of the country, it can also be assumed that such cases will become more common in the future. One should however consider the significance of the volume of the lakes in relation to the magnitude of vehicular traffic. The pollution risk is naturally greatest when heavily-travelled highways pass alongside of or through small lakes. Large lakes and watercourses are considerably less sensitive to pollutants due to their greater volume and water turnover.

Of the pollutants that are dispersed from highways, the traffic, in the form of accidents and oil spills, probably constitutes the greatest threat to surface water supplies. In the water supply at Böksjön (Kolmården) the normal oil spillage from traffic is already causing definite problems (verbal information from A. Tjeder, city of Norrköping). On the other hand, road salting does not appear to cause any drastic increases in the chloride levels of surface water. One example of this is Bornsjön in Botkyrka, where the highway E3/E4, Stockholm-Södertälje passes alongside the southeastern shore of the lake. The lake is a reserve water supply for the Stockholm region, and the Stockholm Water and Sewage Department has conducted studies for the past 20 years on certain parameters in the lake, including the chloride content [25]. It is evident from these studies that road salting has caused a quite moderate increase in the chloride content from 8-10 mg/l at the end of the 1950's to ca. 15 mg/l during the 1970's (Fig. 39).

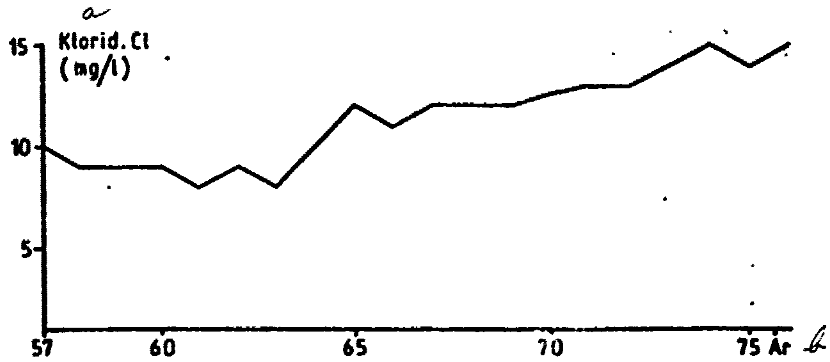


Fig. 39. Increase in the chloride level in lake Bornsjön due to the use of de-icing salt [25].

Key: (a) chloride (b) year

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